Sewage Research

STUDIES ON THE CLARIFICATION STAGE OF THE ACTIVATED SLUDGE PROCESS *

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Introduction

The clarification stage of the activated sludge process refers to the rapid initial removal of materials contained in sewage. This stage of the process is usually completed within an hour, and is distinguished from the slower process that takes place subsequently, which is essential for the maintenance of successful continued purification. The basic facts relating to the initial rapid stage of purification are not subject to controversy. But these facts have been variously interpreted. A critical review of the various views regarding the mechanism of clarification has been given by Theriault.[6] Two generally divergent schools of thought have developed. One group, led by consideration of the rapidity and similarity of the rate of clarification to physical reactions, has attributed clarification to such physical phenomena as coagulation, adsorption, or base exchange. They have assumed that biological reactions could not proceed rapidly enough to be responsible for the initial rapid clarification and have considered it necesssary to invoke some preliminary process of adsorption. It has been generally assumed that colloidal as well as soluble materials are adsorbed by the floc during this stage and subsequently oxidized by the microorganisms and that the successful continuation of the clarification and adsorption process depends upon the oxidation of the adsorbed materials on the floc. Under this conception the biologically active floc has a double function. In the clarification stage it serves as an adsorbent and in the oxidation stage it serves as an inoculum. It has further been accepted that during the clarification stage, oxidation is not the predominating mechanism.

The biological concept of clarification has had a few adherents, among whom Buswell [1] has taken a definite stand regarding the absence of adsorbed matter in the sludge particles, and has attributed purification to the activities of microorganisms which constitute a large part of the sludge floc.

The recently expressed biozeolite theory of Theriault [8] has apparently explained the clarification stage by a base exchange mechanism. Without going into a detailed critical review of the theory it should be mentioned that a purely base exchange mechanism should not demon-

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strate the known effects of antiseptics such as formalin and toluene in definitely checking the clarifying power of the sludge. In view of this as well as other questions arising from the theory, it was considered of some importance to make further studies on the clarification stage of activated sludge. The first part of this paper comprises a study of the removals by activated sludge of certain organic and inorganic substances similar to those occurring in sewage. An attempt will be made to show whether such substances are removed and, if so, the rate of their removal. It was hoped that as a result of this study a suitable substance could be selected to substitute for sewage in clarification studies. The urgent nature of this last phase of the problem was called to attention by Mohlman.[3] If the adsorptive power of activated sludge could be evaluated in a way similar to activated carbon one of the unknown factors in the purification of sewage by activated sludge could be predetermined and standardized.

The second part of the study will deal mainly with some of the factors involved in the clarification of sewage by activated sludge. The third part of the study will deal with rates of oxidation in the clarification stage.

I. Removal of Certain Inorganic and Organic Substances by Activated Sludge

Method

A few substances similar in nature to soluble and colloidal materials present in sewage were selected. These consisted of inorganic substances such as infusorial earth and kaolin, as representative of the clays, and silt present in sewage. Ammonium chloride was included, as a soluble inorganic salt of special interest. Of the organic substances, casein, egg albumen and peptone were used as representing the nitrogenous constituents of sewage, and dextrose and butyric acid as the non-nitrogenous constituents. Removal of bacterial suspensions by activated sludge was considered of additional interest. Appropriate concentrations of these materials in suspension or solution were mixed with returned sludge. Since aeration is generally considered unessential for adsorption, the materials were mixed with activated sludge for various periods by means of horizontal paddles. The open surface, however, afforded possibility of the introduction of small amounts of air. Certain experiments were conducted to compare such mixing with aeration. At the end of different periods of contact the sludge was allowed to separate for 3 minute periods, either by sedimentation of by centrifuging, and the residual amount of the substance in question was determined by appropriate method. By comparing these values with the initial determination, immediately after mixing, the amounts removed were determined.

Results

1. Infusorial Earth.—In Table I are given the results of turbidities obtained by mixing and aerating infusorial earth with activated sludge

TABLE I.—*Removal of Infusorial Earth* by Activated Sludge†*

Minutes	Turbidity Mixed P.p.m.	Turbidity Aerated P.p.m.
0	160	160
5	125	110
10	125	110
15	125	110
20	120	110
25	100	100
30	100	100

* Infusorial earth suspension, 250 p.p.m.

† 20 per cent of sludge by volume from Hillsdale (October 8) and 80 per cent of the above suspension.

for different periods of time. The turbidities decreased rapidly during the first five minutes of mixing or aeration and thereafter they decreased more slowly. Aeration accelerated somewhat the removal of the turbidity with shorter periods of contact but after 30 minutes the results for both mixing and aeration were identical. In Table II are

TABLE II.—*Removal of Infusorial Earth by Activated Sludge*

Minutes Mixing	Hillsdale* October 10	Madison, Chatham* October 15
	Turbidity P.p.m.	Turbidity P.p.m.
0	160	190
15	125	120
30	125	120
45	110	100
60	100	95

* Infusorial earth suspension, 250 p.p.m.

given the results obtained by stirring sludge from Hillsdale and Madison-Chatham with infusorial earth. The sludge from Hillsdale collected October 10, 1935, gave essentially similar results as the sludge from the same plant collected October 8th. The initial turbidity using the same amount of infusorial earth (250 p.p.m.) was higher with Madison-Chatham sludge than with Hillsdale sludge, but subsequent removals were more rapid and approximately the same residual level of turbidity was attained after one hour of mixing.

The discrepancy between the turbidity added and that recovered after immediate mixing with sludge should be attributed to the following factors: (1) The dilution of the turbidity by the clear liquor of the sludge. This would bring down the turbidity in a 20 per cent return sludge mixture from 250 to 200 p.p.m. (2) Possible immediate adsorp-

tion of the turbidity. The Hillsdale sludge consistently gave an immediate reading of 160 p.p.m. when mixed with 250 p.p.m. infusorial earth and 20 per cent returned sludge, instead of a turbidity of 200 p.p.m. However, infusorial earth is not a stable suspension; it will settle more or less readily and therefore the discrepancy between the turbidity of the diluted suspension and the initial mixture with activated sludge after settling cannot be considered significant. Another factor to be considered is the turbidity imparted by some sludges by the breaking up of the loosely held floc particles on handling and mixing with water. With the Madison-Chatham sludge there was considerable amount of such stray particles in suspension after settling, which might compensate in part for the settling of the infusorial earth. For these reasons infusorial earth was not considered as suitable material for these studies.

2. Kaolin.—Stable kaolin suspensions were prepared by adding sufficient N/10 alkali to adjust the reaction to a pH of 7.6 to 7.8 and diluting the suspension with water to the desired concentration. The suspension was centrifuged for 10 minutes at 2300 r.p.m. and the stable supernatant was used for mixing with activated sludge. To overcome the turbidity of the stray activated sludge particles the mixtures were centrifuged for 3 minutes at 1800 r.p.m. By this procedure it was possible to remove the turbidity of the sludge particles without affecting appreciably the residual turbidity due to kaolin. In subsequent experiments with kaolin this technic was followed. Mixing different concentrations of kaolin with returned sludge for a period of an hour gave only small removals of turbidity (Table III). The removals in p.p.m.

TABLE III.—*Removal of Kaolin by Activated Sludge*

	Mixtures			Minutes Mixing			
	Sludge *	Kaolin †	Water	0	15	30	60
	c.c.	c.c.	c.c.	Turbidity P.p.m.			
1	200	800	0	200	190	160	160
2	200	400	400	90	85	80	75
3	200	200	600	60	55	50	50

* Return sludge from Morristown.

† Kaolin 10 gram/L., pH adjusted and centrifuged. Kaolin suspension, without sludge, made to the same total volume as the mixture 1 = 215 p.p.m., 2 = 105 p.p.m., 3 = 60 p.p.m. turbidity.

were higher with the larger concentrations of kaolin. It is also interesting to note that the turbidity of the kaolin suspension, without sludge, made up to the same volume as the sludge mixtures, was slightly higher than the turbidities of the mixtures after immediate mixing. Thus the removal immediately after mixing was of minor importance when the necessary precautions were taken.

In the next experiment the amount of kaolin was kept constant and

the volume of sludge changed. The sludge volume was varied from 60 to 20 per cent. The removal of turbidity was not appreciably affected by the volume of returned sludge (Table IV) and the removals of the turbidity with an hour of stirring were small.

TABLE IV.—*Removal of Kaolin by Different Amounts of Activated Sludge*

	Mixture			Turbidity, P.p.m., One Hour Mixing		
	Sludge *	Kaolin †	Water	0	30	60
1	600	400	0	125	100	190
2	400	400	200	100	95	90
3	200	400	400	110	95	90

* Return sludge from Morristown, same as in Exp. 3, stored in ice box for 1 day.
† Kaolin 10 grams/L., pH adjusted and centrifuged.

In the following experiment the capacity of removal of kaolin turbidity by different sludges was compared. Bernardsville sludge, with a low suspended solids concentration, settled only to 82 per cent, giving a sludge index of 418 (Table V), while Morristown sludge had a sludge

TABLE V.—*Removal of Kaolin by Different Returned Sludges*

Sludge				Kaolin	Water	Turbidity, P.p.m. Minutes Mixing		
Source	Settling	Susp. Solids	Volume			0	30	60
	%	p.p.m.	c.c.	c.c.	c.c.			
1. Bernardsville	82	1960	1000	400	0	145	110	95
2. Morristown	43	4070	500	400	500	145	110	90
3. Madison-Chatham	80	5560	315	400	700	95	80	70
4. Hillsdale	87	4400	450	400	550	100	80	65

index of 105, Madison-Chatham 144, and Hillsdale 198. Different volumes of the sludges were mixed with kaolin to give approximately the same suspended solids concentrations. There was no definite relation between the sludge index and removal of kaolin turbidity, with the exception of Bernardsville sludge, which had the highest sludge index as well as the highest residual turbidity. Morristown sludge, with the lowest sludge index, had next to Hillsdale the lowest turbidity. The differences in the initial turbidities with the different sludges, when using the same quantity of kaolin, should be ascribed to the turbidities of the original sludge liquors.

A part of the sludge used in this experiment was aerated and another part stored without air for a period of two days. They were then mixed with kaolin in the proportions given in Table V and their clarifying power determined by the procedure outlined above. The

results are given in Table VI. Aeration for two days did not improve the clarifying power of the Bernardsville sludge and had little effect on the clarifying power of Morristown and Madison-Chatham sludge. Storage without air destroyed the clarifying power of Morristown sludge and had little effect on Madison-Chatham sludge.

TABLE VI.—*Effect of Aerating and Storing Returned Sludge on the Clarifying Power*

	Turbidity, P.p.m., Minutes Mixing		
	0	30	60
1. Bernardsville Aerated	125	100	95
2. Morristown Aerated	110	100	85
3. Madison-Chatham Aerated	110	95	75
4. Morristown Not Aerated	195	195	195
5. Madison-Chatham Not Aerated	110	90	80

It was thought of interest to compare the clarifying power of different sludges for kaolin and sewage. Returned sludge from Bernardsville, Morristown and Madison-Chatham were compared. Sufficient volume of each sludge was taken to give approximately 2000 p.p.m. suspended solids when mixed with kaolin or sewage. The volumes of the different components in the mixture and the turbidities after different periods of mixing are given in Table VII. Bernardsville sludge

TABLE VII.—*Comparison of the Clarifying Power of Returned Sludge for Kaolin and Sewage*

	Suspend. Solids P.p.m.	Sludge C.c.	Kaolin	Sewage	Water	Turbidity, P.p.m., Minutes Mixing		
						0	30	60
1. Bernardsville	1755	1100*	400	0	400	215	230	215
2. Morristown	3770	510*	400	0	400	190	140	95
3. Madison-Chatham	9370	200	400	0	400	160	125	105
4. Bernardsville	1755	1100*	0	800	0	160	140	140
5. Morristown	3770	510*	0	800	0	105	95	95
6. Madison-Chatham	9370	200	0	800	0	95	75	70

* Concentrated to 200 c.c. by centrifuging.

did not remove the turbidity of kaolin but reduced somewhat the turbidity of the sewage. The turbidity due to kaolin was reduced by 95 p.p.m. and that of sewage only by 10 p.p.m. by Morristown sludge. A greater removal of kaolin turbidity than sewage turbidity was also obtained by the Madison-Chatham sludge. The sludges showed differences in the initial turbidities, with either kaolin or sewage. The highest initial turbidity, both with kaolin and sewage, was with the Bernardsville sludge and the lowest with Madison-Chatham. The turbidity of the original sludge liquor or the immediate removal of turbidities might explain these differences. It is clear, however, that the same sludge clarifies sewage and kaolin to different degrees.

Removals of kaolin turbidity observed in the above experiments by admixture with activated sludge could not be attributed to oxidation. Yet air might play a role in these removals by keeping the floc in an active state. In order to determine the role of air in the removal of kaolin turbidity by activated sludge the effect of agitating the mixtures by diffused air and nitrogen gas was compared. The results with three different sludges indicate that kaolin turbidity was removed to a greater extent when air was used for agitation than with nitrogen gas (Table VIII).

TABLE VIII.—*Removal of Kaolin Turbidity by Air and Nitrogen Gas*

	Air			Nitrogen		
	Initial	½ hr.	1 hr.	Initial	½ hr.	1 hr.
Madison-Chatham, September 25	195	145	125	195	160	160
Madison-Chatham, September 28	195	90	100	195	140	140
Madison-Chatham, October 2	240	—	150	240	—	220

3. Butyric Acid.—The rate of removal of butyric acid, when added to activated sludge in dilute solutions and mixed in a stirring machine, was determined. After definite periods of mixing the sludge was removed by centrifuging and the residual acidity determined by titration with .02N alkali. Results as indicated in Table IX show very little removal of acidity when 250 p.p.m. of the acid was used, giving a pH of 4.5, but with 75 p.p.m. of the acid, giving a pH value of 6.5, both Madison-Chatham and Hillsdale sludge gave considerable removals within an hour. Bacterial activity was greatly retarded at a pH 4.5 but with the lower concentration of butyric acid there was probably not much retardation.

TABLE IX.—*Removal of Butyric Acid by Activated Sludge*

	Butyric Acid Added	Milli-Equivalents of Acid per Litre				
		Minutes Mixing				
		0	15	30	45	60
	P.p.m.					
Hillsdale	250	2.28	2.08	2.24	2.16	2.24
Madison-Chatham	75	.80	.80	.70	.68	.54
Hillsdale	75	.82	—	.70	—	.66

4. Dextrose.—Claims have been made in the literature that soluble materials such as sugars are adsorbed by activated sludge and removed from solution prior to their decomposition. In order to determine whether such action takes place, 300 c.c. of 1000 p.p.m. dextrose solution was added to 200 c.c. portions of three different returned sludges.

The sludge was kept in suspension by manual agitation for various periods. Portions were centrifuged and reducing sugars determined. The removal of dextrose within an hour did not exceed over 10 per cent of the original sugar content of the mixture. As bacterial activity was not prevented these removals might readily be attributed to direct bacterial decomposition.

5. Casein, Peptone and Egg Albumen.—Casein and egg albumen were treated with .2N NaOH to obtain a suspension and the pH adjusted to 6.8. The suspension was filtered to remove the coarser particles. Peptone was dissolved in water. These liquors were then mixed with returned sludge. After mixing for different periods the sludge was separated by centrifuging, the liquor filtered through paper to free it from straggling floc and total nitrogen determinations were made on the filtrate. The control consisted of the same suspensions of egg albumen, casein and peptone diluted with the centrifuged and filtered sludge liquor to the same volume as the sludge mixtures. The results with two different sludges are given in tables X and XI. It

TABLE X.—*Removal of Casein and Peptone by Mixing With Activated Sludge* *

	Hours	Total N, P.p.m.	N Removed, P.p.m.
1. Casein 75 per cent + act. sl. filtrate 25 per cent	Initial	61.0	—
2. Casein 75 per cent + act. sl. 25 per cent	"	59.0	2.0
3. Casein 75 per cent + act. sl. 25 per cent	½	58.5	2.5
4. Casein 75 per cent + act. sl. 25 per cent	1	59.0	2.0
5. Peptone 75 per cent + act. sl. filtrate 25 per cent	Initial	77.5	—
6. Peptone 75 per cent + act. sl. 25 per cent	"	78.0	.0
7. Peptone 75 per cent + act. sl. 25 per cent	½	77.4	.1
8. Peptone 75 per cent + act. sl. 25 per cent	1	77.4	.1

* Returned sludge from Morristown, 5900 p.p.m.

TABLE XI.—*Removal of Casein, Egg Albumen and Peptone by Mixing With Activated Sludge*

	Hours	Total N, P.p.m.	N Removed, P.p.m.
1. Casein + sl. liquor	Initial	52.6	—
2. Casein + sl.*	"	—	—
3. Casein + sl.	1/2	46.2	6.4
4. Casein + sl.	1	46.2	6.4
5. Egg albumen + sl. liquor	Initial	40.2	—
6. Egg albumen + sl.	"	34.4	5.8
7. Egg albumen + sl.	1/2	35.8	4.4
8. Egg albumen + sl.	1	—	—
9. Peptone + sl. liquor	Initial	62.6	—
10. Peptone + sl.	"	60.2	2.4
11. Peptone + sl.	1/2	61.2	1.4
12. Peptone + sl.	1	60.2	2.4

* Ret. sludge from Hillsdale 13,800 p.p.m., 20 per cent by volume in mixtures.

will be seen that casein and egg albumen were removed to a greater extent than peptone. The greatest removal occurred immediately after mixture with the sludge. The removal of total materials should be considerably higher than is indicated by the total nitrogen values.

6. Removal of NH_3–N by Activated Sludge.—When to a dilute NH_4Cl solution, returned sludge was introduced and mixed, there was no removal of ammonia for a period of an hour, as is indicated in Table XII. The results are representative of many unsuccessful trials to

TABLE XII.—*Removal of Ammonia by Mixing With Activated Sludge* *

Source of Sludge	Ammonia N, P.p.m.			
	In Original Sludge	In Mixtures, Hours Mixing		
		0	1/2	1
1. Morristown	45	45	45	45
2. Morristown Washed	5.5	35	35	35
3. Hillsdale	2	35	35	35

* Mixtures made by adding 25 per cent by volume of different sludge to NH_4Cl solution containing 45 p.p.m. NH_3-N.

show an adsorption of ammonia by activated sludge. It was considered that owing to the equal concentration of ammonia in the original sludge and the solution added there was no possibility for adsorption. Hence the concentration of ammonia in the sludge was reduced to 5.5 p.p.m. by washing, without avail. The lower NH_3–N content of the washed mixtures, as compared with the unwashed sample, was due to the low ammonia content of the sludge itself. In fact, the calculated value from the volumes and concentration of ammonia corresponds exactly with the observed values. Therefore there was no possibility of an immediate removal of NH_3–N by the initial contact with sludge. The sludge from Hillsdale, which had an originally low NH_3–N content, similarly gave negative results in regard to adsorption of NH_3–N. The Hillsdale sludge was well stabilized and contained 4.0 p.p.m. NO_3.

The original ammonia content of the sludge was reduced to 0.5 p.p.m. by filtering through a zeolite filter and then treated with NH_4Cl water. Stirring the sludge mixture for an hour, still did not give any removal of NH_3–N.

An attempt was made to convert the ammonia of the sludge to nitrate by constant aeration, with concordant determination of adsorption of the NH_3–N added, but along with the increase in nitrates the ammonia content of the sludge increased during ten days of aeration, and therefore the experiment was not conclusive.

Returned sludge was then regenerated with NaCl prior to treatment with ammonium chloride solution. The sludge was centrifuged and the supernatant liquor poured off. The residue was suspended in 4

per cent NaCl solution two successive times and the chlorides washed out with NH_3-free distilled water. The ammonia content of the sludge was thus reduced from 45 to 3 p.p.m. The results with the sludge thus prepared, when mixed with ammonium chloride water, are compared below with the sludge not thus treated:

	Sludge Per Cent	NH_4Cl* Water Per Cent	Minutes Mixing		
			0	30	60
			NH_3N		
			P.p.m.	P.p.m.	P.p.m.
Untreated	15	85	14	14	14
Regenerated	15	85	6	6	6

* NH_4Cl water, 7 p.p.m.

The calculated values, from the volumes and ammonia contents, of the sludge and ammonium chloride water, should be 12.7 and 6.2 p.p.m. for the untreated and treated mixtures, respectively. Again there was no indication of an immediate or even a slow adsorption of ammonia by mixing sludge with an initial low ammonia content with ammonium chloride water.

In order to determine whether activated sludge had adsorbed NH_3, the sludge was subjected to three successive washings (1) with NH_3 free water and (2) with NH_3-free water containing 4 per cent NaCl. 500 c.c. portion of the sludge was shaken each time with 1500 c.c. of the above waters, allowed to settle, and the supernatant decanted. The results are given in Table XIII.

TABLE XIII.—*NH_3-N Recovered by Washing Activated Sludge*

	Washed With NH_3-Free Water		Washed With 4 Per Cent NaCl Soln.	
	Added Mgm.	Recovered Mgm.	Added Mgm.	Recovered Mgm.
Sludge, Original	.9		.9	
1st Wash		.525		.75
2nd Wash		.075		.187
3rd Wash		.075		.037
Sludge, Final		.05		.05
		.725		1.024

The recovery of NH_3–N by three washings of the sludge with NH_3-free water was not complete. Washing the sludge with dilute sodium chloride solution gave somewhat higher recovery than the original NH_3–N content of the sludge. This increase amounts to only 0.2 p.p.m. on the basis of the original sludge volume and might be within the ex-

perimental error. It is evident, however, that the use of NaCl hastens the recovery of NH_3–N from the sludge.

7. Removal of B. Coli by Activated Sludge.—It was considered of interest to determine whether mixing bacterial suspensions with activated sludge for short periods results in removal of bacteria. B. coli was grown on agar surface for 24 hours. The growth was suspended in phosphate buffer water. The suspension was centrifuged and the bacterial residue was re-suspended in water and filtered. The above precautions were taken in order (1) to remove soluble materials extracted from the agar, and (2) to eliminate as far as possible the bacterial clumps which might interfere in subsequent bacterial count. The suspension thus prepared, suitably diluted and mixed with returned sludge, was allowed to settle, and bacterial counts were made on the supernatant. Two other portions of similarly treated sludges were stirred and aerated for 10 minutes and bacterial numbers were determined on the supernatant after ½ hour sedimentation. The results given in Table XIV show somewhat lower counts on mixing the sludge

TABLE XIV.—*Removal of B. Coli Suspensions by Stirring or Aerating with Activated Sludge*

	Bacteria* in Millions
1. 80 per cent B. Coli suspension + 20 per cent water	40.0
2. 80 per cent B. Coli suspension + 20 per cent ret. sl. initial	35.2
3. 80 per cent B. Coli suspension + 20 per cent ret. sl. after 10 min. aeration	38.0
4. 80 per cent B. Coli suspension + 20 per cent ret. sl. after 10 min. mixing	46.0

* 4-day agar plate counts.

with B. coli suspension and allowing it to settle, than the same bacterial suspension diluted to a similar volume with water. Aerating or mixing thereafter resulted in an increase in the bacterial numbers of the supernatant. The experiment was repeated in essentially the same way, leaving out the stirring. Two different concentrations of B. coli suspensions prepared as described above were mixed with the same volume of sludge and aerated for ½ hour. The results in Table XV indicated an immediate removal of bacteria by mixing of returned

TABLE XV.—*Removal of B. Coli Suspension by Aerating With Activated Sludge*

	High Concentration,* Millions	Low Concentration,* Millions
1. 80 per cent B. Coli suspension + 20 per cent water	84	10.5
2. 80 per cent B. Coli suspension + 20 per cent ret. sl. initial	65	1.6
3. 80 per cent B. Coli suspension + 20 per cent ret. sl. after 1/2 hr. aeration	73	5.0

* 4-day agar plate counts.

sludge with B. coli suspensions and allowing it to settle. This effect was more marked with the lower concentration of bacteria. Aerating these mixtures for ½ hour resulted in an increase of bacterial numbers of the supernatant.

8. Effect of Agitation and Washing on the Bacterial Numbers of the Supernatant of Activated Sludge.—The increase of bacterial numbers in the supernatant with continued stirring suggested the possibility that bacteria might pass from the sludge to the liquid under the influence of mechanical agitation. A cylinder containing returned sludge was inverted four times and allowed to settle one-half hour. Bacterial counts were made on the supernatant. This process was repeated four times with two different sludges. The results are given in Table XVI. Gentle agitation brought about by inverting the cylinder resulted in an increase of bacteria in the supernatant.

TABLE XVI.—*Effect of Agitation on the Bacterial Numbers of Returned Sludge Supernatant*

	Bacteria in Thousand * per c.c.	
	Sludge No. 1	Sludge No. 2
1st agitation	34	18.7
2nd agitation	50	16.0
3rd agitation	57	18.0
4th agitation	61	25.0

* 4-day agar plate counts.

The next inquiry was to determine the effect of washing the sludge with water on the bacterial numbers of the supernatant. The problem consisted in disturbing the equilibrium of the bacterial numbers in the sludge by bringing the sludge into contact with a liquid of lower bacterial concentration. Accordingly, returned sludge was mixed with water, allowed to settle, and bacterial numbers of the supernatant were determined after ½ hour sedimentation. The supernatant was siphoned off and replaced with fresh water and the process repeated a number of times. The results are given in Table XVII. Each succeeding wash water contained at least as many bacteria as the original

TABLE XVII.—*Removal of Bacteria of Activated Sludge by Washing*

	Bacteria in Thousand per c.c.*		
	Hillsdale Sludge	Madison-Chatham Sludge	
		Sl. No. 1	Sl. No. 2
1. Original sl. liquor	44	221	187
2. 1st wash	119	252	260
3. 2nd wash	106	293	260
4. 3rd wash	62	—	210

* 4-day agar plate counts.

sludge liquor. Bacteria are therefore readily removed from the floc, especially when the equilibrium is disturbed by exposure to a liquid containing a lower bacterial concentration. These bacteria are probably not the zooglea-forming organisms of Butterfield [2] since they are said to be unable to grow on agar plates. Evidence will be produced in the following part to show that washing in a similar way breaks up the floc and increases the turbidity and organic nitrogen content of the wash water. It is reasonable to assume that the increase in bacteria is associated with the breaking up of the floc and does not take place as a result of the migration of the organisms.

Discussion

Removal of Inorganic Materials.—It has been shown that inert materials, such as infusorial earth and kaolin, when mixed for a period of an hour with activated sludge, are removed from suspension. Materials of similar nature occur in normal sewage as clay and silt from surface wash. That such particles, if small enough, can form the nucleus for growth of activated-sludge organisms has been shown by Whitehead and O'Shaughnessy.[9] They have further indicated an improvement in the quality of effluent and in the rate of settlement of activated sludge by the addition of red marl. We have determined similarly the effect of addition of kaolin, infusorial earth and clay on the settlement of returned sludge and demonstrated that to obtain an appreciable effect, as much as 1000 p.p.m. of these materials must be used. However, the addition of these materials to sewage or sewage and sludge mixtures failed to improve the clarification on aeration (unpublished results).

That air is essential for the removal of such inert materials has also been demonstrated. When nitrogen is passed through sludge it is to be expected that deflocculation takes place, resulting in an increase of the turbidity of the supernatant. It is possible that for a short period the passage of nitrogen gas may have the resultant effect of these two tendencies (for the sludge to break up and for the inert material to be removed), finally the first tendency predominating. Aeration, however, for a short period will not cause the deflocculation of activated sludge and may in addition and/or in consequence increase the rate of removal of these inert substances.

The removal of kaolin by activated sludge seems to be affected by the initial concentration of the kaolin but is not influenced by the amount of sludge in the mixture, within the range employed (20 to 60 per cent by volume).

The removal of kaolin by different sludges varied but could not be correlated, except in broadest terms, with the sludge index nor could it be correlated with the clarification of sewage by the same sludge. For these reasons the use of this substance as a suitable substitute for sewage in a clarification test is not to be recommended. The prime requirement for such a substance would be that it should give similar results as sewage and that the rating of the clarifying power of acti-

vated sludge by such a substance should be the same as for sewage. Infusorial earth could not be used for this purpose because of the instability of the suspension. By special precautions stable kaolin suspensions could be prepared. The technic developed made it possible to remove the turbidity of non-settling floc particles without affecting the turbidity of the kaolin.

Removal of Organic Materials.—Organic materials such as butyric acid, dextrose, peptone, casein and egg albumen were removed to a small extent when mixed with activated sludge. Since the magnitude of these removals was small and these substances are readilly attacked by microorganisms it is not possible to attribute these removals to adsorption during the clarification stage.

Removal of Bacteria.—In regard to bacterial removal by activated sludge, the results indicated than when B. coli suspensions were mixed with activated sludge and allowed to settle, removals varying from 12.5 to 85 per cent were obtained. Since the sludge liquor contributed some bacteria to the suspension, the actual removals were probably somewhat higher. On further mixing and aerating, no additional removals were obtained but an increase in the numbers. The higher figure was obtained with lower initial bacterial concentration. Rubentschik *et al* [5] obtained over 90 per cent adsorption of certain bacteria when suspensions were shaken for one minute with liman (salt lake) mud. The values they obtained were higher than the results reported here. They, however, used 2 grams of mud to 10 c.c. of the bacterial suspension. The fact that with lower initial bacterial counts relatively larger numbers of bacteria are removed might indicate a relationship between the initial bacterial numbers and the amount of sludge. The above investigators showed that the adsorption of bacteria was influenced both by the initial concentration of bacteria and the quantity of the mud. In regard to desorption of bacteria they found that on shaking the mud with a bacterial culture for periods varying from 5 to 300 seconds, the percentage of desorption increased from 0.6 to 6.2. Our results show in a similar way an increase in the number of bacteria in the supernatant after the initial rapid mixing. We have further shown that when sludge was washed successively with water, the number of bacteria removed from the sludge into the water was greater than the original number in the sludge liquor. These bacteria were probably not the zooglea-forming type described by Butterfield,[2] which do not grow in nutrient agar, but some of the foreign bacteria attached to the sludge floc. It is interesting to speculate that excessive handling of the sludge such as in pumps might cause a rise in the bacterial numbers of the supernatant liquor.

With reference to the removal of ammonia by activated sludge, repeated experiments have been negative. Reducing the ammonia content of the sludge by washing, zeolite treatment and regeneration with NaCl did not make the sludge capable of removing ammonia. Theriault [7] obtained adsorption of ammonia by dried sludge. He indicated, however, the desirability of making the test with liquid sludge. The

necessary precautions enumerated by him were observed without success. The adsorption theory advanced by Parsons and Wilson [4] was not based on the adsorption of ammonia by activated sludge but on organic impurities as measured by oxygen consumed. The curves presented by Parsons and Wilson do not indicate an appreciable removal of NH_3–N during the first hour of aeration. Their experiments were made by actually passing air through the liquid, and therefore the conditions for the removal of NH_3–N were somewhat more favorable than by mixing. Referring to their curves on the removal of NH_3–N and organic impurities, they state that these are two entirely different reactions. In view of these facts it would seem that the removal of ammonia by activated sludge is not a physical phenomenon.

Summary

Suitably prepared suspensions of infusorial earth and kaolin were stirred with activated sludge for a period of one hour to determine the removal of these substances as an index for the clarification of sewage by activated sludge. Although the turbidity was removed to a certain extent, no correlations would be made between these removals and the clarifying power of the sludge for sewage or the sludge index.

Organic substances such as dextrose, peptone, casein and egg albumen were also removed by stirring with activated sludge but since biological action was not precluded the action could not be ascribed to adsorption. When a suspension of B. coli was mixed with activated sludge and allowed to settle, the numbers left in the supernatant were less than the original suspension diluted with water to a similar volume. Mixing or aerating the mixture for a period of 10 to 30 minutes did not result in a further reduction but an increase. In a more dilute suspension the bacterial removals were relatively higher. Replacing the sludge liquor with water and allowing the mixture to settle for three successive times removed each time a number of bacteria greater than the original number in the sludge liquor.

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SOME FUNDAMENTAL FACTORS CONCERNED IN THE OPERATION OF TRICKLING FILTERS *

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Our investigation of trickling filters during the past few years had its inspiration in a desire to test a theory which we had formulated from general observations on the operation of trickling filters and from the published literature in this field. The theory may be broadly stated as follows: If trickling filters are dosed continuously with a rain-like spray, they should function efficiently at certain high rates when sufficient water is applied to carry away the accumulated organic matter, while the same filters should pond at certain lower rates of application. Furthermore, filters dosed continuously with a rain-like spray should give high degrees of purification at daily average rates considerably above those commonly employed today.

Experimental work was initiated primarily to verify the above hypothesis. As the work progressed, it became apparent that factors other than distribution and dosage were involved and that an understanding of the problem required an investigation of these as well. We wish here to report on three of these factors: distribution, aeration, and mold growth.

Distribution

From the standpoint of hydraulics, one would expect that the thickness of the film of water in the filter, as the sewage passes through, would be of considerable importance in determining the degree of purification. In a plant with long rest periods and poor distribution, the film thickness should be considerably greater than in a similar plant with the same loading that operates without rest periods and with good distribution. It may be possible, by eliminating rest periods and improving the distribution, actually to decrease the film thickness while at the same time increasing the load. In considering this problem we have found it necessary to set up some arbitrary definitions in order to evaluate this factor with some semblance of a quantitative measure.

The *daily average dose* we define as the total amount of sewage applied to the filter bed in the course of one day divided by the total surface area of the filter. We will, for our purposes, define the momentary rate of application for any given square foot as the volume of sewage being distributed over that square foot of filter area during one second. The *maximum momentary rate* will be the largest amount falling on it during any second of normal operation. It is of course apparent that the value for one square foot or for one second will have little value and that an average value must be taken. However, if we take an average over the area of the whole bed we have the daily average. But we are

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interested in having an index of the distribution efficiency. We will therefore average the values of the maximum distribution ratios only over the areas which are being most heavily dosed. The *mean maximum momentary rate* we then define as the average value of the maximum momentary rates determined over those areas that will constitute the smallest possible portion of the filter surface that receives half of the total flow of sewage. With the usual type of fixed nozzle distributors, measurements would be made within the annular rings on which the bulk of the waste falls; with a rotary distributor, they would be made on any half of the filter that receives half of the total waste. The maximum momentary rate may be measured by means of a pan 1 square foot in area. With rotary distributors, the pan is placed on the filter surface while the distributor arm moves over it once. According to our definition, then, the volume of liquid in the pan indicates the maximum momentary rate for that particular area. Obviously, the volume in the pan will depend upon the number and speed of the distributor arms. With the fixed nozzle type, the pan is placed in the annular ring, and by means of a stop watch, the length of time that the spray hits the pan is determined. Knowing this time, and the volume in the pan, one can determine the maximum momentary rate. The volume will depend on the design of the distributor nozzle and also on the design of the dosing tank.

We have also introduced another term, the *distribution ratio,* by which we mean the ratio of what the daily average rate of application would be if sewage were applied to the entire surface of the filter at the mean maximum momentary rate of application continuously for 24 hours to what the average daily rate of application actually is. We have measured the distribution ratios of a number of filters. The following results are typical:

Filter No.	Size	Distributor	Daily Average Flow (Gals.)	Distribution Ratio
1.	85′ diam.	Rotary	200,000	77.8
2.	128′ diam.	Rotary	212,500	165.8
3.	128′ diam.	Rotary	212,500	221.3
4.	128′ diam.	Rotary	212,500	152.2
5.	128′ diam.	Rotary	212,500	242.2
6.	84′ diam.	Rotary	75,000	341.0
7.	135′ diam.	Rotary	575,000	31.2
8.	40′ diam.	Rotary	32,000	35.9
9.	80′ diam.	Rotary	220,000	22.5
10.	80′ diam.	Rotary	70,000	119.2
11.	80′ diam.	Rotary	260,000	34.0
12.	90′ diam.	Rotary	175,000	44.6
13.	69′ diam.	Rotary	170,000	85.5
14.	75′ diam.	Rotary	150,000	182.0
15.	57½′ diam.	Rotary	60,000	75.0
16.	80′ × 75′	Fixed nozzles	125,000	48.0
17.	102′ × 80′	Fixed nozzles	400,000	29.0
18.	90′ × 90′	Fixed nozzles	200,000	52.0
19.	158′ × 102′	Fixed nozzles	280,000	45.0
20.	120′ × 110′	Fixed nozzles	300,000	54.0

Of the trickling filters now in operation, the minimum distribution ratio which we have observed is 22.5, and it frequently runs up to several hundred. The average for plants throughout the middle west is about 100.

The real question involved in our original hypothesis is whether it is possible to increase the daily average rate of application without affecting the degree of purification. We felt at the beginning of our work that it should be possible to increase the daily average rate to 20 million gallons per acre per day and still get good reduction if the distribution ratio is decreased almost to unity. The data to be presented later will show the results that have been attained under these conditions.

Aeration

During the progress of our work we observed that aeration may at times be inadequate, and that special steps must be taken to improve it. This forced us to investigate the factors that are responsible for the flow of air. Three factors have been found to be of some importance: (1) the cooling or heating of the air by the liquid; (2) the change in density of the air brought about by changes in humidity; and (3) heating due to microbial activity in the filter.

In our experimental filters that have been operating continuously at high daily average rates, the heating effect due to microbial activity appears not to be of any great importance. The first two factors, however, do come into play. The third factor probably plays a part in the aeration of trickling filters that are operated intermittently, since in such a bed considerable digestion of organic matter takes place. Filters operated continuously at high daily average rates act primarily as flocculators, and little, if any digestion is encountered. It will be of considerable interest to determine whether the digestion which occurs in orthodox filters has a bearing on the aeration. We have given this question some study, but have not as yet been able to come to any definite conclusions as to the amount of aeration which may thus be set up. This question will be considered in more detail in a later publication.

In order to study the factors affecting air flow, we constructed in the laboratories of the Department of Chemical Engineering of the University of Minnesota, a small filter, 2½ ft. in diameter, 6 ft. deep, filled with gravel of an average diameter of 1¾ inches. The gravel was selected so as to get a uniform size. The filter was dosed with water by a distributor which allowed us to vary the dosage from 2 to 30 million gallons per acre per day. The temperatures of the incoming and outgoing air and water were measured by means of thermometers. The flow of air was measured by a hot wire anemometer. By means of this filter, we were able to determine the effect of temperature differences between the water and air upon the rate of flow of air, and also the differences in air flow during continuous and intermittent operation. Details of this work will appear in a publication coming from the Department of Chemical Engineering.

Results of this work indicate that aeration in this filter is brought about primarily by the cooling or heating effect of the liquid upon the air. If the temperature of the air is higher than that of the liquid, there will be a downward draft. If the reverse is true, the draft will be upward. If there is no difference in temperature, the flow of air will be very slight, the movement then depending primarily upon the differences in humidity of the air inside and out. For dosages up to 20 million gallons, the rate of flow of air is independent of the dosage, and is a straight-line function of differences in temperature of the air and water (Fig. 1). This straight-line relationship is attained only after

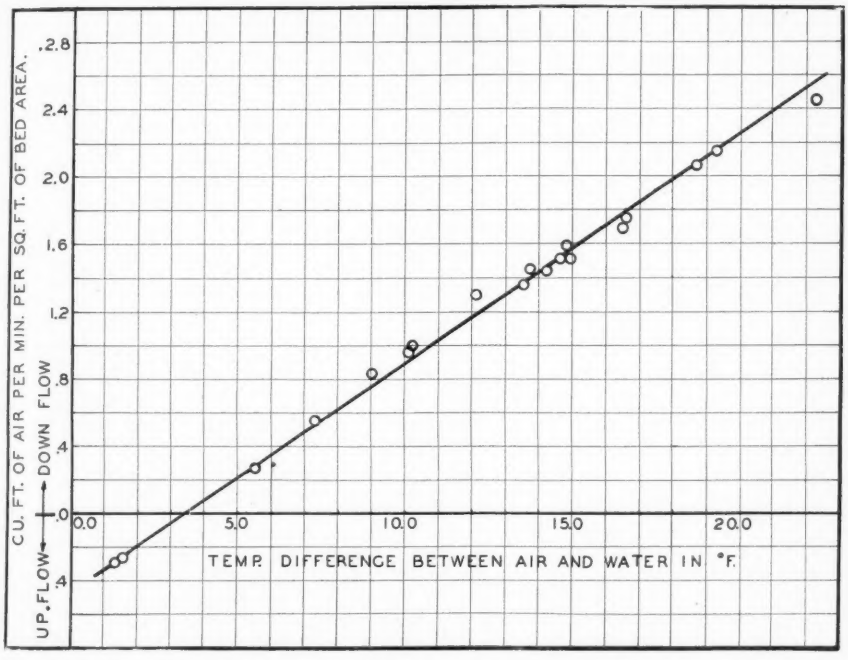

FIG. 1.—Relation between flow of air through experimental filter and temperature difference between air and water.

the bed has operated for a sufficiently long time to reach equilibrium conditions. With high dosages, equilibrium is reached quickly, but with low dosages, the bed has to be operated for a considerable length of time. With low dosages, unless the bed has reached equilibrium, the rate of flow of air is erratic and low.

During intermittent operation, sharp changes in rate of air flow are noted during the dosing period. During rest periods, the rate is dependent upon humidity relationships and temperature differences between the bed and the air. After the bed has operated long enough to reach equilibrium, the air flow should be the same during dosing and resting periods. The effect of intermittent operation is well illustrated in Figures 2 and 3. The results indicate that during seasons when the

temperatures of air and sewage are about the same, there is danger of insufficient aeration in ordinary trickling filters. During those seasons, forced draft should be used.

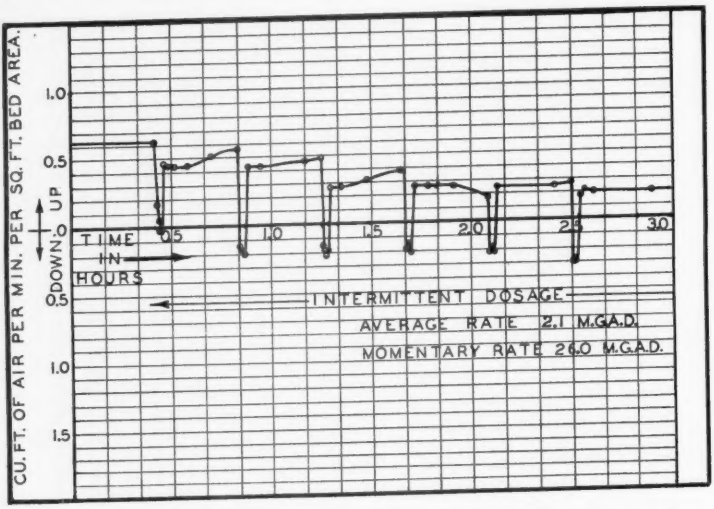

FIG. 2.—Air flow with intermittent dosage, average rate 2.1 m.g.a.d.

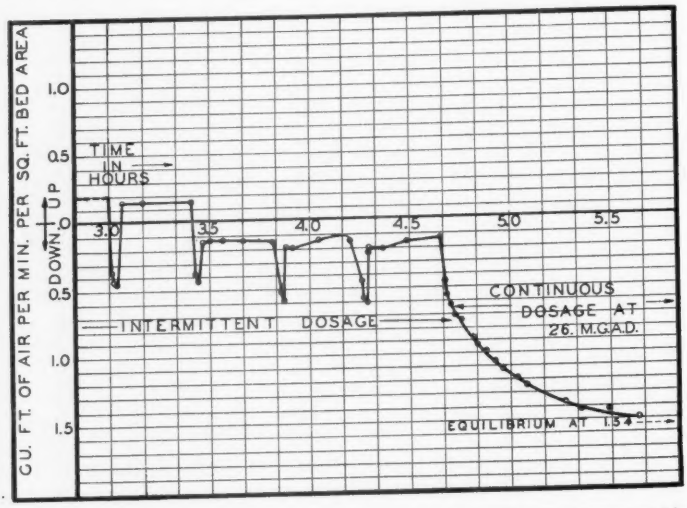

FIG. 3.—Air flow with intermittent dosage at low rate and continuous dosage at high rate.

GROWTH OF MOLDS

Even though a filter is so operated that it has perfect distribution and adequate aeration, and even though the strength of the sewage is not unreasonably high, certain biological factors may have to be controlled if the filter is to give good results. We have found that certain types of waste stimulate the growth of molds, namely *Fusaria.* These

fungi may grow so profusely that they plug a filter that would otherwise remain open. The growth may cover large areas of the filter, it may plug orifices, pipe lines and pumps. We have encountered these molds when attempting to treat sewage that contained malting plant waste. They are most troublesome in the winter months. The *Fusaria* are not so adversely affected by low temperatures as bacteria and are therefore better able to compete with bacteria during the winter. The reverse seems to be the case in the summer. Also, winter sewage contains fewer soil organisms among which there are species of bacteria that parasitize molds. This is indicated by our ability to check this mold growth in one of our plants by resorting to soil inoculations. In this plant, wherever *Fusaria* began to appear, we inoculated the sewage by dumping a pail of soil into the raw sewage for several days in succession. After such inoculations, the *Fusaria* disappeared.

Experimental Procedure and Data

The effect of the three factors—dosage, aeration, and excess mold growth—can be observed from our experimental data. Before presenting these data, however, we wish to describe briefly our experimental plants and the technique used in carrying out our studies.

Studies were conducted on three experimental plants, the earliest being made on what we have called the Oak Street plant, which was in operation for about a year and a half. This was a rock filter, 8 ft. in diameter and 8 ft. deep, filled with crushed granite of a size ranging from 1½ to 3 inches. It was dosed with pre-settled sewage by means of a disc distributor. There was a primary settling tank, but no final settling tank. No provision was made for forced draft. The sewage was a combination of industrial and municipal waste, the bulk of industrial waste apparently coming from a malting plant. After the abandonment of the Oak Street plant, studies were continued on what we have called the Lake Street plant. Here there were three filters, each 6 ft. in diameter and 8 ft. in depth. Two were filled with gravel measuring 1½ to 3 inches, and one was filled with vitrified clay tile. A primary settling tank was provided for each filter, and a final settling tank was provided for one of the gravel filters. Each filter was dosed by means of a disc distributor. The Lake Street plant was operated for about a year. This publication is confined to the results obtained on the gravel filters. The results on the tile filter will be reported later in a publication dealing with another phase of the problem. Studies were also made on an experimental plant used for the treatment of creamery waste. This plant has been described in a previous publication, and since no additional data are available for presentation here, we shall merely refer the reader to that publication for a description of the work on this plant.* We might state, however, that the plant is now being used to take care of all the waste from the creamery, and is operating successfully. All these experimental plants have been dosed continuously, with the exception of the Oak Street plant which, for a

*"Aero-Filtration of Sewage and Industrial Wastes." By H. O. Halvorson. *Water Works and Sewerage*, September, 1936.

period of about two months, was dosed intermittently. The dosage rate has been varied somewhat, but in general it has been either 10 million gallons per acre per day or 20 million gallons, or above, per acre per day. In all plants the distribution ratio has been approximately unity.

This work was started primarily as an academic problem, and with insufficient funds to carry out complete laboratory studies on daily composite samples. We therefore decided at the outset of the work to forego a complete analysis and to focus our attention on a single measurement which could be accepted as a reliable criterion of efficiency of treatment. Although we have made some determinations of suspended solids, total nitrogen, nitrates, nitrites, and pH values, we have for the most part limited analytical work to determination of B.O.D. values, and have relied for guidance almost entirely on these values and on visual observations. B.O.D. determinations have for the most part been confined to four-hour composite samples, obtained by sampling every 15 minutes. Since the flow of waste was constant and continuous, it was not necessary to adjust the samples for variation in flow. We have found very good agreement in the percentage of reduction of grab samples and the four-hour composite samples. Twenty-four hour composites were taken in a few instances, and these showed good agreement with the four-hour samples so far as percentage reduction in B.O.D. was concerned. The absolute value of B.O.D., however, was smaller for the 24-hour composite, largely because the four-hour samples were taken during the day when the sewage was at its maximum strength. In all studies, samples were taken of the influent to the filter, the effluent from the filter, and in some instances, the effluent from the final settling tank at the Lake Street plant. Samples of effluent from the filter were allowed to settle in the laboratory for two hours. This gave results which agreed very closely with the results obtained on samples of effluent from the final settling tank, which was large enough to give a detention period of two hours. The percentage reduction reported indicates the reduction in B.O.D. from the influent to the filter to the settled effluent. The graphs following the tables give a visual picture of variation in reduction from month to month, and also temperature variations of the air and of the liquid.

Oak Street Plant.—The Oak Street plant was put in operation about the middle of May, 1934, and was dosed continuously at 10 m.g.a.d. until the 25th of June (Fig. 3 and Table I). From then until the 16th of August, it was dosed continuously at from 22 to 26 m.g.a.d. On the 16th of August, the dosage was decreased to 10 m.g.a.d., and operated at that rate until October 1. At that time the dosage again was increased to 26 m.g.a.d., and the plant was operated continuously at this rate until February 15, 1935, with the exception of a short period during October when the plant was shut down for the purpose of allowing the accumulated organic matter to digest. Following this digestion, the bed was hosed for several hours. On the 15th of February, 1935, the plant was put into intermittent operation at a daily average rate of 4 m.g.a.d.

TABLE I.—*Oak Street Plant. Results of Operation*

Date	Dosage M.g.a.d.	B.O.D.		Percentage Reduction
		Influent	Effluent	
1934				
June 7	10	195	102	48.0
25	10	193	85	56
27	26	152	67.5	55.7
July 13	26	215.5	46	78
20	26	148.5	28.5	81
27	22	142	17.4	88.1
Aug. 3	22	144.5	16.9	88.3
16	10	177.5	15.6	91.2
24	10	170.5	7.3	95.6
29	10	196	10.6	94.6
Sept. 7	10	127.5	22.3	82.5
12	10	90.0	12.6	86.4
19	10	135	36.3	73.1
21	10	166.5	56.3	66.2
26	10	120	24.0	80.0
Oct. 1	26	61	22.15	63.7
5	26	186	74.4	59.9
24	26	129	56.8	56.0
26	26	166.5	35.1	78.9
30	26	215.5	78.3	63.7
Nov. 3	26	237	74.3	70.5
7	26	238	72.8	69.0
9	26	278.5	132.3	52.5
16	26	187.5	104.3	44.3
20	26	98.0	61.0	37.8
Dec. 8	26	152.5	94.0	38.4
20	26	228	137.4	39.8
26	26	210	131	37.6
28	26	203.5	102	49.8
1935				
Jan. 14	26	225	132.5	41.1
18	26	167	81.25	51.3
Feb. 9	26	135	68.8	49.1
15	4 (intermittent)	179	106	40.5
20	4	142.5	78.3	45
21	4	87.5	55	37.2
22	4	158	81	48.7
23	4	106	67.0	33.7
Feb. 25	4	111	46.3	58.3
26	4	89	54.5	37.8
27	4	89.5	48.6	45.8
28	4	113.4	65.9	41.9

TABLE I.—*Continued*

Date	Dosage M.g.a.d.	B.O.D.		Percentage Reduction
		Influent	Effluent	
Mar. 4	4	99.5	45.6	54.2
6	4	71.7	47.0	34.4
7	4	70.0	20.9	70.2
9	4	72.8	32.3	55.7
11	4	92.0	26.0	71.8
12	4	84.0	29.0	65.5
13	4	88.3	24.8	71.9
18	4	67.7	16.8	75.2
22	4	198	75.9	61.5
23	20 (continuous)	89	45.8	48.6
28	20	121	100	23.7
Apr. 3	20	182	134	26.4
9	20	134	89	33.6
15	20	150	93	38.0
16	20	86.5	39.0	55
18	20	120	67	44
19	20	137	76	44.5
27	20	123	68	45.7
30	20	100	59	41
May 1	20	100	64	36
2	20	71	43	39.4
4	20	131	88	32.8
6	20	156	88	43.6
7	20	156	93	40.3
8	20	116	65	44
9	20	211	111	47.4
10	20	150	52	65.3
14	20	119	41	65.5
17	20	108	42	61.6
18	20	180	65	63.9
20	20	181	100	44.2
22	20	220	140	52.7
28	20	173	63	64.2
29	20	158	52	67.3
31	20	156	60	60.2
June 3	20	122	30	75.4
5	20	169	68	59.7
18	20	148	16	89.1
20	20	138	22.2	84
25	20	141	25	82.3
July 1	20	127	11	91.3
9	20	154	12.8	91.5
13	20	91	5.7	93.8
Aug. 3	20	146	13.6	90.5
16	20	184	13.6	92.4
17	20	190	61	68.0
23	20	226	70	69.0

This was continued until March 22. At that time, the bed was again put into continuous operation at 20 m.g.a.d., and operated at that rate until the final shut-down.

Lake Street Plant.—The Lake Street plant was put in operation the latter part of August, 1935 (Fig. 4 and Table II). Filters I and III

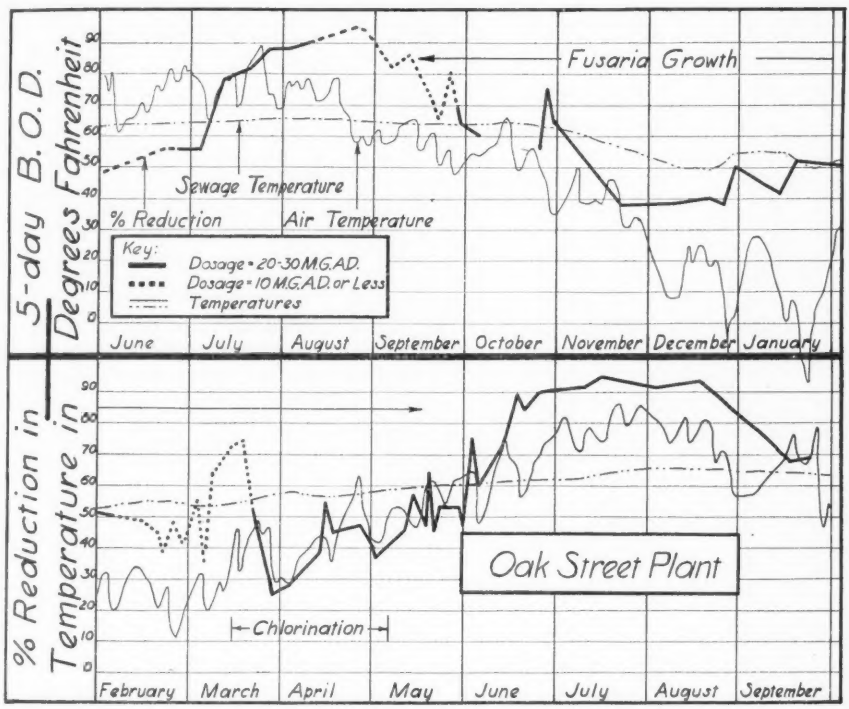

FIG. 4.—Results of operation of Oak Street Plant, June, 1934, through September, 1935.

were the same, with the exception of some slight variations in dosage and aeration, Filter I being equipped with forced draft whereas Filter III was not. Filter III was dosed continuously at 20 m.g.a.d. or above for a period of a year. There were, however, two periods during which we experienced motor difficulties, and as a result the plant was operated interruptedly. The first period occurred from the middle of March to the middle of May, and the second period during the month of July. Filter I was put in operation at 20 m.g.a.d. or above, and operated at that rate until October 17. At that time the dosage was reduced to 10 m.g.a.d. or less until November 13. The dosing was then increased to about 20 m.g.a.d., and operated at this rate for the balance of the year, with the exception of three periods of shut-down. The first occurred in February, the second from the middle of March to the middle of May, and the third during the month of July. The periodic shut-downs occurring in March, April, and May, and again in July,

TABLE II.—*Lake Street Plant. Results of Operation*

Filter I

Date	Sewage Temp.	Flow M.g.a.d.	B.O.D.				Nitrite	Nitrate
			Inf.	Shaken Eff.	Settled Eff.	Per cent Red.	(Effluent)	
1935								
Sept. 4....		25	171		44	74		
11....	68° F.	25	159		49	69		
18....	68	25	207		34	83.5		
23....	68	20	335		42.4	87.4		
27....		20	171		33.8	80		
Oct. 1....	64	20	167		39	76.6		
8....	65	20	185		53.3	71.3		
14....		20	188		37.1	80.3		
15....		20	337		38.2	88.7		
16....	63.8	20	213		52.7	75.1		1.04 p.p.m.
17....		20	182		24.9	86.2		
25....		10	167		30.8	81.4	0.5 p.p.m.	1.3
28....	60.5	8.5	252		16.3	93.6	0.75	1.85
29....	61	12.5	132		21.2	83.9	0.5	0.5
31....	54	6.5	68		17.4	75.0		
Nov. 2....	58	7.7	175		60.5	65.1	0.75	1.45
11....	56	16.7	126		37.2	70.5	0.70	1.10
13....	58	20.0	142		34.9	75.3		
14....	58	20.0	118		33.2	71.9		
15....	58	17.4	129		32	75.2	0.4	1.4
18....	56	19.1	124		18.4	85.1	0.4	0.4
20....	56	16.7	141		36.4	74.2		
22....	54	22.2	143		36.1	74.7	0.4	1.0
25....	54	16.0	107.5		42.5	60.5	0.4	0.6
27....	54	20.0	154		28.9	81.2		
30....	56	16.7	250		63.5	74.6		
Dec. 2....	54	18.2	262.5		64.0	79.4	0.4	1.0
4....	52	16.7	214.5		48.7	77.2	0.4	1.4
6....	54	21.1	138		37.1	73.1	0.7	0.7
11....	52	21.1	256		64.5	74.8		
13....	54	22.2	245					
16....	55	20.0	407		101	75	0.6	0.4
18....	52	21.1	195		50	74.4	0.6	0.6
23....	52	20.0	410		88	78.5		
27....	52	20.0	320		76+		0.75	1.05
30....	54	20.0	700		105	85.0		
1936								
Jan. 3....	54	20.0	315		53.4	83		
6....	54	20.0	640		202+			
8....	54	26.6	280		87.5	68.7		
10....	52	26.6	410		72.5	82.3		
13....	54	16.7	580	190	137.5	76.3	0.75	0.45
15....	52	26.6	240	138	55	78.0		
17....	52	26.6	330	145	101	69.4		
20....	52	26.6	780	335	205	72.4		
24....	52	26.6	370		82.5	77.7		

TABLE II.—*Continued*

Date	Sewage Temp.	Flow M.g.a.d.	B.O.D.				Suspended Solids	
			Inf.	Shaken Eff.	Settled Eff.	Per cent Red.	Shaken Inf.	Shaken Eff.
Jan. 27....	52° F.	26.6	675	235	180	73.3		
29....	52	26.6	310	120	80	74.2	180 p.p.m.	176 p.p.m.
Feb. 24....	52	20.0	625	530	210	66.4	1366	618
26....	52	20.0	320	190	100	68	314	250
28....	52	23.5	320	175	105	67.2	624	152
Mar. 2....	50	20.0	580	285	127.5	78.0	798	532
6....	46	22.2	365	750	62.5	82.9	514	1302
9....	46		625		80	87.2	1134	1462
May 18....	52	23.5	390	180	105	73.3		
20....	54	20.0	300	140	65	78.3	442	164
22....	56	26.6	295	120	57.5	80.5	380	148
25....	54	21.1	413+	154	55.5	86.6	718	238
29....	56	23.5	252	175	35	86.1	300	410
June 1....	58	21.1	310	275	47.5	84.7	386	606
3....	56	16.7	300	102	55	81.7	344	86
8....	58	18.2	430	160	64	85.1	162	210
10....	58	15.4	240	200	17.5	92.7		
12....	60	21.1	350	290	35	90.0		
15....	58	23.5	480	127	70	85.4	956	350
17....	60	22.2	275	152	54	80.2	748	380
22....	60	18.2	594	180	118	80.1	824	146
24....	61	22.2	322.5	90	43.2	86.9	682	184
July 20....	70		178	74	54	69.6	182	98
22....	67	26.6	75	45	29	61.3	118	56
24....	66	22.2	126.5	44.5	43.2	65.8	96	26
27....	68	20.0	145	80	56.5	61.0	122	60
29....	66	20.0	137	47.7	42.7	68.8	64	18
31....	67	20.0	86	19.8	17.4	79.8	76	2
Aug. 3....	69	20.0	110	61.2	56.2	48.9	50	15
5....	67	20.0	85	16.7	16.2	80.9	74	5
7....	69	20.0	182.5	62.5	66.2	63.7	74	12
10....	73	21.1	402	198	161	60.0	258	130
12....	71	20.0	155	48.5	48.5	68.7	122	38
14....	71	21.1	141.5	32.2	25.0	82.3	73	24
17....	70	20.0	174.5	47.0	39.5	77.3	104	29
19....	67	20.0	69.5	48	28.2	59.4	48	56

were caused by the spring thaw or rain which brought about flooding in the plant. This flooding resulted in the breakdown of motors that occurred in July.

DISCUSSION OF RESULTS

From the tables and curves it is apparent that poor results were obtained during June at the Oak Street plant when we were dosing at 10 m.g.a.d. The plant showed considerable improvement while it was being dosed at the high rates, but the efficiency again fell off when the rate was put back to 10 m.g.a.d. We are not able to conclude that the decrease in efficiency was due entirely to the low rate because we encountered difficulty with the growth of *Fusaria* at about the same time

that the efficiency began to drop. Because of the growth of these organisms, we were unable to obtain successful operation during the entire winter. It was not until the following spring when the *Fusaria* sud-

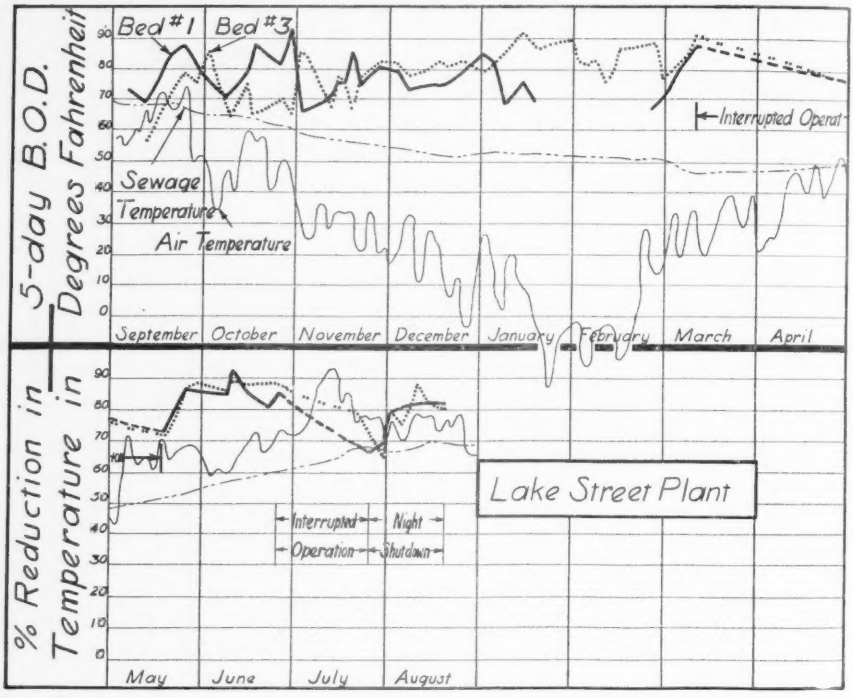

FIG. 5.—Results of operation of two filters at the Lake Street Plant, September, 1935, through August, 1936.

denly disappeared that the plant again began to function efficiently. During the winter months we attempted to control the growth of these organisms by various methods, but were unsuccessful. We appeared to have some success with soil inoculation, which was tried in the early part of March, but did not continue this practice long enough to reach definite conclusions. We felt, however, that the disappearance of *Fusaria* in the spring was influenced by the increased amount of soil carried in the sewage because of the spring rains.

Both filters at the Lake Street plant gave very promising results not only in the fall and spring but also during the winter months. Bed I, which had forced draft, gave better results during September and October than Bed III without forced draft. During November and December, both gave about the same results; in January and February, however, Bed III without forced draft gave better results than Bed I. We are convinced that forced draft during the winter months is injurious. Soil inoculation was resorted to in this plant whenever *Fusaria* began to appear, and following such inoculation, the *Fusaria*

Lake Street Plant

Filter III

Date	Sewage Temp.	Flow M.g.a.d.	B.O.D.				Nitrite	Nitrate
			Inf.	Shaken Eff.	Settled Eff.	Per cent Red.	(Effluent)	
1935								
Sept. 11....	68° F.	25	159		70	56		
18....	68	25	207		60	71		
23....	68	25	335		73	78.1		
27....		25	171		43.2	75		
Oct. 1....	64	25	167		24	85.6		
8....	65	25	192		69.4	64		
14....		25	251		59.5	76.3		
15....		25	122		43.4	64.4		
25....		25	96		29.2	69.8	0.2 p.p.m.	1.4 p.p.m.
28....	60.5	21.1	46		16.3	64.6	0.35	0.85
29....	61	21.1	144		26.7	81.4	0.40	0.40
31....	54	21.1	140		21.0	85.0		
Nov. 2....	58	20.0	175		26.0	85.1	0.55	0.15
11....	56	16.7	126		41.1	67.3	0.65	0.95
13....	58	22.2	142		31.6	77.7	1.00	0.50
14....	58	22.2	122		25.0	79.5		
15....	58	16.7	129		30.0	76.7	0.50	0.00
18....	56	21.5	110		19.6	82.2	0.50	0.70
20....	56	26.6	112		25.1	77.7		
22....	54	25.0	116		63.9	44.8	0.50	1.50
25....	54	18.2	107				0.40	0.60
27....	54	23.5	217.5		38.5	82.3	0.30	0.50
30....	56	20.0	295		70.0	76.3		
Dec. 2....	54	19.0	282.5		52.5	81.4	0.20	0.20
4....	52	19.0	236.5		44.3	81.4	0.20	1.60
6....	54	18.2	150		33.8	77.5	0.70	0.20
9....	52	18.2	292.5		61.5	79.1	0.50	0.00
11....	52	18.2	252.5		53.0	79.0	0.50	0.70
13....	54	17.5	239		53.5	77.6		
16....	55	18.2	408		71	82.6	0.50	0.70
18....	52	17.5	195		38	80.5	0.60	0.50
23....	52	20.0	310		54	82.6	0.65	1.50
27....	52	20.0	345		72	78.8	0.70	0.70
30....	54	20.0	545		113	79.3		
1936								
Jan. 3....	54	20.0	315		58.6	81.0		
6....	54	19.0	620		125.0	79.8		
8....	54	17.5	320		47.5	85.1		
10....	52	13.3	300	105	27.5	90.0		
13....	54	26.6	560	95	47.5	91.5		
15....	52	16.0	240	117.5	60.0	74.4		
17....	52	17.5	290	195	37.5	87.0		
20....	52	16.0	730	385	102.5	86.0		
24....	52	15.4	350		40.0	88.6		
27....	52	17.5	650	160	70.0	89.2		

FILTER III.—*Continued*

Date	Sewage Temp.	Flow M.g.a.d.	B.O.D.				Suspended Solids	
			Inf.	Shaken Eff.	Settled Eff.	Per cent Red.	Shaken Inf.	Shaken Eff.
Jan. 29....	52° F.	17.5	340		35	89.7	296 p.p.m.	88 p.p.m.
31....	50	19.0	360		62.5	82.6	452	124
Feb. 3....	52	22.2	610	190	115	81.1		
5....	52	20.0	410	140	70	83.0	210	118
7....	52	20.0	350	130	60	82.9	356	132
10....	52	20.0	630	200	155	75.4	692	140
12....	52	19.0	420	160	85	79.8	611	116
14....	51	17.5	380	120	65	87.0	626	166
17....	52	18.2	615	65	77.5	87.4	382	290
19....	50	21.1	390	100	50	87.2	560	152
21....	50	19.0	310	75	47.5	84.7	638	164
24....	52	18.2	625	130	75.0	88.0	1420	152
26....	52	21.1	320	170	37.5	88.3	314	116
28....	52	23.5	370	115	82	77.0	636	152
Mar. 2....	50	19.0	560	205	110	80.4	818	138
6....	46	22.2	380	190	60	84.2	480	138
9....	46		550	130	47.5	91.3	1128	200
May 18....	52	23.5	390	175	110	71.7		
20....	54	20.0	310	135	60	80.6	406	154
22....	56	25.0	320	145	65	79.7	366	218
25....	54	17.5	413	146	51.7	87.5	836	226
29....	56	21.1	235	155	27.5	88.3	222	310
June 1....	58	21.1	330	300	57.5	82.6	410	670
3....	56	16.7	305	118	57.5	81.1	344	152
8....	58	17.5	455	139	65	85.7	448	118
10....	58	15.4	290	70	30	89.6		
12....	60	15.4	360	95	31.2	91.3		
15....	58	19.0	512	82	61	88.0	802	164
17....	60	20.0	275	85	32.5	88.1	746	184
22....	60	17.5	554	125	58	89.5	966	146
24....	61	20.0	299	94	38.7	87.0	666	284
July 20....	70		253	69	52	79.4	430	94
22....	67	22.2	67	40	26	61.2	72	74
24....	66	20.0	107	49	30.2	72.1	58	34
27....	68	20.0	145	137	115.0	20.9	94	116
29....	66	21.1	123	50	44.2	64.2	70	6
31....	67	20.0	78.7	24.5	15.2	80.7	42	0
Aug. 3....	69	20.0	112	52.7	44.5	60.4	54	23
7....	69	20.0	202.5	68.1	51.2	74.7	92	20
10....	73	20.0	436	79	56.3	87.4	278	72
12....	71	20.0	161.5	38.3	28.5	82.3	116	27
17....	70	20.0	179	87	71.5	60.5	64	62
19....	67	20.0	95.5	32.0	17.7	81.5	68	64
21....	72	19.0	80.0	23	23.5	70.5	272	51

disappeared. We are not ready to conclude that the growth of *Fusaria* can be controlled in all types of wastes, by soil inoculation, but we certainly did succeed in doing so in the waste which was treated at the Lake Street plant.

It is interesting to compare the Oak Street and Lake Street plants as we have done in Figure 6, which clearly shows the effect of soil inoculation upon the growth of *Fusaria* and the percentage reduction

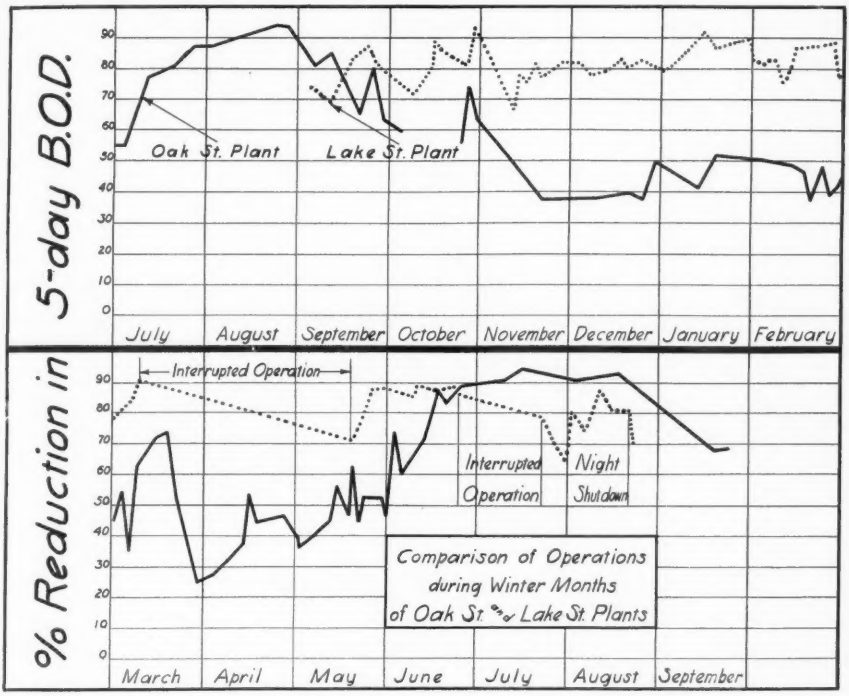

FIG. 6.—Per cent reductions of 5 day B.O.D. at Oak Street and Lake Street Plants.

in 5-day B.O.D. It is also interesting to note from this comparison that the Oak Street plant which operated continuously during August gave much better results than the Lake Street plant during the same month when it was operated during the day and allowed to rest at night. We are convinced that long rest periods are definitely injurious to trickling filters.

FUTURE WORK

The experimental work is being continued through the coming year. Studies are to be carried out on two plants constructed to treat all the waste from two separate communities, of about 3000 and 1200 population. The one plant will be put in operation about November 1, and the other about December 1. Laboratory control data will be collected on both these plants, and results will be published as soon as available. Both filters will be dosed at rates varying from 10 to 30 million gallons per acre per day.

ONE YEAR'S OPERATION OF AN EXPERIMENTAL HIGH-RATE TRICKLING FILTER

By F. W. Mohlman

Director of Laboratories, The Sanitary District of Chicago

An experimental high-rate trickling filter has been operated by The Sanitary District of Chicago at the West Side Treatment Works since September, 1935. The West Side sewage is settled in Imhoff tanks and the effluent is discharged to the Main Channel. The experiment was undertaken to determine how much additional purification could be obtained, by use of a high-rate filter, and to permit observation of its operation. Conferences were held, during the construction of the filter, with Dr. H. O. Halvorson of the University of Minnesota and Mr. Wm. Buckley of the Simplex Ejector Corporation, Chicago. Their suggestions concerning construction and operation of the filter have been followed and they have been continuously informed of the results of operation.

Description of Filter and Settling Tank

The filter is 20 ft. in diameter, enclosed in a circular wooden tank 9½ ft. deep (Fig. 1). The underdrains are formed by 3 by 8 in. timbers set on edge 18 in. center to center. A grill of 2 by 2 in. timbers

Fig. 1.—Experimental high rate trickling filter.

with ⅞ in. clear openings is laid over the bottom beams, and the stone is placed on the 2 by 2 in. timbers. The bottom of the tank slopes to the center with a pitch of ¼ in. per foot; the effluent flows between the 3 by 8 in. timbers to the center outfall pipe.

The stone is a dolomitic limestone, from 2 by 3½ in. in size with a small proportion less than 2 in. in diameter.

Results of twelve screen analyses showed:

Diameter of Hole, Inches	Per Cent Retained
3	23.8
2½	38.5
2	25.7
1½	10.0
1	2.0

The depth of stone is 8 feet.

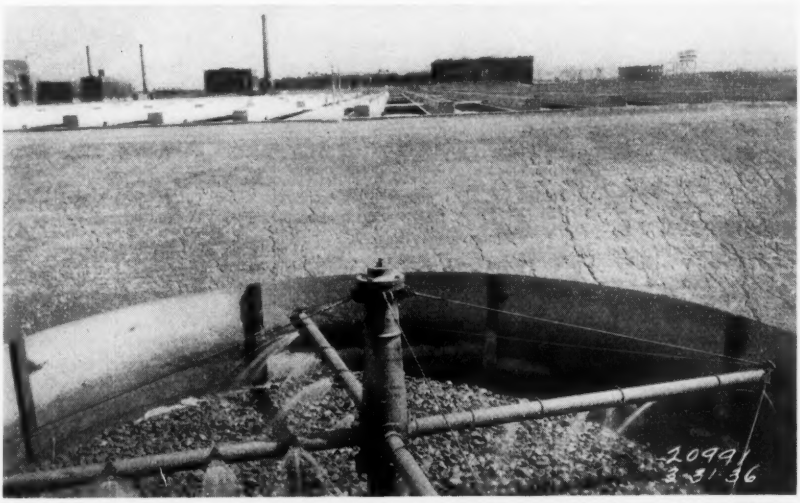

FIG. 2.—Imhoff tanks in background, distributor and surface of high rate trickling filter in foreground.

The settled sewage is sprayed continuously on the bed by a Simplex rotary distributor with four arms (Fig. 2). There are four nozzles on each arm, and the sprays from each nozzle are controlled by an adjustable flap. The distributor revolves at 6 r.p.m. at a dosage of 23 m.g.a.d. and 7½ r.p.m. at 26.6 m.g.a.d. Effluent can be re-circulated by means of a 2½ by 2½ in. centrifugal pump.

Artificial aeration can be obtained by means of a suction fan, which draws air down the filter through the open end of a 4 inch pipe which terminates at the center of the tank.

Settled sewage is pumped to an orifice box several feet above the filter and measured through orifices. A head of 2 ft. 9 in. operates the revolving distributor.

The hopper-bottomed final settling tank is 12 ft. in diameter and 11 ft. deep. The hopper slopes at 1.36 vertical to 1.0 horizontal to the central sludge draw-off pipe. Sludge as withdrawn is measured in a calibrated box. The effluent trough is inside the tank and is notched with V-notches for withdrawal of effluent.

Schedule of Operation

Imhoff effluent was applied to the filter. The West Side sewage during most of the year 1936 has been very dilute, and the settling period in the Imhoff tanks has been excessively long, because many sewers had not been connected to the interceptor and only a small portion of the design flow was received at the plant. However, even at capacity flow the sewage will be comparatively dilute.

Samples of raw sewage, Imhoff effluent, filter effluent and final settled effluent have been collected by means of automatic samplers. Daily analyses have been made.

In planning the schedule of operation, it was decided to operate the filter for a long period at a fixed rate, rather than to change the rate frequently for short-time observation. Studies of re-circulation and of artificial aeration were planned for one or more months' duration, since no duplicate control filter was available.

Rate of Filtration and Re-circulation of Effluent.—The rates of filtration and re-circulation are shown in Table I. For a full year the

Table I.—*Operation of High-Rate Trickling Filter*
Rate of Filtration and Re-Circulation

Month 1935–36	Hours in Operation per Day Ave.	Rate of Filtration M.G.A.D. Effluent	Per Cent Recirculation	Rate of Filtration M.G.A.D. Including Recirculation
September 11–30	23.8	20.2	13	22.9
October	23.7	20.2	15	23.2
November	23.8	20.2	14	23.0
December	23.0	20.2	15	23.2
January	23.9	20.2	15	23.2
February	23.8	20.2	0	20.2
March	23.9	20.2	0	20.2
April	24.0	20.2	0	20.2
May 8–31 *	23.0	20.2	0	20.2
June	23.2	20.2	0	20.2
July	22.1	20.2	0	20.2
August	23.2	20.2	0	20.2
September	23.9	26.6	0	26.6

* Shut down April 30 to May 8, 1936.

rate was 20.2 m.g.a.d., in September, 1936, this rate was increased to 26.6 m.g.a.d. Effluent was re-circulated for the first five months, in amount from 13 to 15 per cent of the volume of incoming settled sewage.

Attention is directed toward the record of hours of operation per day, usually between 23 and 24. Experimental filters of this small size are often shut down from time to time, thus destroying the continuity of operation, but this filter operated practically continuously.

Temperatures and Artificial Aeration.—The temperatures of air

and sewage are given in Table II, likewise the periods of artificial aeration. Dr. Halvorson suggests the use of artificial aeration when tem-

TABLE II.—*Operation of High-Rate Trickling Filter*
Temperatures and Artificial Aeration

Month 1935–36	Temperatures, Deg. F				Artificial Aeration	Dates
	Sewage		Air			
	Filter Inf.	Filter Eff.	Filter Inf.	Filter Eff.		
September 11–30	70	—	66	—	Yes	20 to 30
October	65	—	52	61	Yes	1 to 31
November	58	—	38	54	Yes	1 to 30
December	51	45	23	48	Yes	1 to 31
January	47	42	17	—	No	—
February	44	39	15	—	No	—
March	47	42	38	—	No	—
April	54	49	43	—	No	—
May 8–31	64	61	66	—	Yes	15 to 31
June	67	64	67	65	Yes	1 to 30
July	74	72	78	72	Yes	1 to 31
August	78	76	76	—	No	—
September	73	72	67	—	No	—

peratures of air and sewage are approximately the same, consequently aeration was started when the filter was put into operation in September, 1935; aeration was continued long after the air temperature dropped below the sewage temperature, however, but was terminated at the end of December, 1935. Artificial aeration was again started in May, 1936, and continued through July. In August, 1936, however, aeration was discontinued, even though temperatures of air and sewage were quite similar, in order to afford a comparison of results with the preceding month, with aeration.

The rate of aeration was 1 cu. ft. per minute per sq. ft. of filter area.

The influence of re-circulation or aeration is discussed later.

RESULTS OF OPERATION

B.O.D. and Suspended Solids.—The monthly results of analyses for B.O.D. and suspended solids are given in Table III. The year's average shows a 5-day B.O.D. of 97 and suspended solids 122 p.p.m. for the raw sewage. The Imhoff tanks reduced the B.O.D. to 47.6 p.p.m. and suspended solids to 47; these reductions are quite high, but are due to the long settling period. The filter effluent frequently showed an increase in suspended solids and occasionally in B.O.D., over the Imhoff effluent, as might be expected during unloading, but the final settled effluent always showed a substantial reduction of B.O.D. and suspended solids, as compared with the Imhoff effluent.

TABLE III.—*Operation of High-Rate Trickling Filter*
Results of Analyses

R.S. = Raw Sewage F.E. = Filter Effluent
I.E. = Imhoff Effluent S.F.E. = Settled Filter Effluent

B.O.D. and Suspended Solids

Parts per Million

Month 1935–36	5-day B.O.D.				Suspended Solids			
	R.S.	I.E.	F.E.	S.F.E.	R.S.	I.E.	F.E.	S.F.E.
*September 11–30	82	36.2	18.5	14.8	120	40	24	20
*October	121	47.2	27.2	18.6	183	52	32	22
*November	97	44.5	61.6	27.7	120	43	87	28
*December	118	66.2	51.6	35.6	119	53	59	28
January	130	59.3	44.0	28.5	128	42	34	24
February	150	74.5	57.8	43.9	158	60	49	36
March	54	30.9	29.1	16.3	74	35	29	19
April	95	52.7	39.0	23.5	124	54	48	30
*May	96	49.3	58.2	27.2	142	56	127	44
*June	82	46.8	53.8	25.5	100	50	70	30
*July	63	34.7	40.7	17.2	89	35	48	23
August	79	28.1	18.5	13.3	102	38	36	23
Average	*97*	*47.6*	—	*24.3*	*122*	*47*	—	*27*
September	71	26.6	75	12.3	107	38	140	16

* Artificial aeration.

The settling period in the final tank was rather short, averaging only 1.0 hour. In September, 1936, this was increased to 1.5 hours by by-passing some of the filter effluent.

The variation in B.O.D. of the final effluent from summer to winter is noteworthy. The results in summer show a B.O.D. of 12.3 to 17.2 p.p.m., which increased to 28 to 44 p.p.m. in winter. This seasonal variation is typical of trickling filter effluents, as discussed by Hatfield, and likewise a similar, although narrower, variation is shown by activated sludge effluents.

Percentage Reductions and B.O.D. Loadings.—The parts per million and percentage reductions by Imhoff tanks and overall are presented in Table IV. These results show large reductions of B.O.D. and suspended solids by sedimentation prior to filtration, averaging 49.8 and 60.8 per cent, respectively. Overall, the reductions average 74.9 per cent for B.O.D. and 77.0 per cent for suspended solids, ranging in B.O.D. from 70 per cent in winter to 83 per cent in summer.

In column 6, Table IV, are given monthly filter loadings in pounds of 5-day B.O.D. removed per acre per day. These results are discussed later.

Nitrogen Data.—It is important to give consideration to the nitrogen data in operation of high-rate filters, to determine whether the second stage of oxidation has been accomplished. The data in Table V show that some nitrification occurred in summer, even at 26.6 m.g.a.d. in September, 1936. However, the degree of nitrification was in gen-

eral rather slight, and there was only a moderate reduction of organic and ammonia nitrogen.

The staleness of the Imhoff effluent during the winter is indicated by the high values for ammonia nitrogen from December through February.

TABLE IV.—*Operation of High-Rate Trickling Filter*
Removal of B.O.D. and Suspended Solids

Month 1935–36	5-day B.O.D.					Suspended Solids			
	Parts per Million Removed by		Per Cent Reduction		Lb. Removed per Acre per Day by Filter plus Final Tank	Parts per Million Removed by		Per Cent Reduction	
	Imhoff Tank	Filter plus Final Tank	Raw to Imhoff Effluent	Raw to Final Effluent		Imhoff Tank	Filter plus Final Tank	Raw to Imhoff Effluent	Raw to Final Effluent
September 11–30	45.8	21.4	55.9	82.0	3600	80	20	66.7	83.3
October	73.8	28.6	60.7	84.7	4813	131	30	71.6	88.0
November	52.5	16.8	43.8	71.5	2827	77	15	64.2	76.7
December	51.8	30.6	43.9	69.8	5150	66	25	55.5	76.5
January	70.7	20.8	54.4	78.0	3500	86	18	67.2	81.3
February	75.5	30.6	50.3	70.8	5150	98	24	62.0	77.2
March	23.1	14.6	42.8	70.0	2457	39	16	52.7	74.3
April	42.3	29.2	44.6	75.3	4914	70	24	56.4	75.7
May 8–31	46.7	22.1	48.7	71.7	3719	86	12	60.5	69.0
June	35.2	21.3	42.9	69.0	3585	50	20	50.0	70.0
July	28.3	17.5	45.0	72.8	2945	54	12	60.6	73.8
August	50.9	14.8	64.4	83.2	2491	64	15	62.7	77.5
Average			*49.8*	*74.9*	*3763*			*60.8*	*77.0*
September	44.4	14.3	62.5	82.7	3170	69	22	64.5	85.0

TABLE V.—*Operation of High-Rate Trickling Filter*
Nitrogen Data
P.P.M. as N

Month 1935–36	Influent to Filter		Final Effluent			
	Org.	Amm.	Org.	Amm.	Nitrite	Nitrate
September 11–30	6.0	11.4	4.1	10.5	0.6	0.2
October	5.1	10.0	3.7	8.7	0.5	0.6
November	6.0	9.2	3.9	8.0	1.0	1.2
December	5.9	12.1	4.0	10.6	0.9	1.3
January	5.5	13.8	3.8	13.2	0.4	0.6
February	5.8	12.8	4.8	12.3	0.1	0.6
March	4.8	6.5	3.3	6.2	0.3	0.8
April	12.1	6.1	7.2	6.8	0.1	0.3
May	9.5	6.5	6.8	6.2	0.9	0.2
June	9.2	8.3	5.5	6.5	2.2	0.4
July	6.4	6.6	3.6	4.0	1.1	2.3
August	7.5	7.8	3.4	3.4	0.9	2.5
September	7.3	5.1	4.6	1.9	0.4	3.7

Discussion of Operation

Unloading.—One of the first and most important questions regarding a high-rate filter is "Will it unload?" The tremendous volume of settled sewage passing through the stone may deposit enough solids within the filter to clog it very quickly unless it unloads freely. This requirement is so important that it led to the decision to use a very coarse stone, conducive to unloading, although of much less surface area than finer stone.

When the filter started in operation, it immediately began to store solids, shown in Table III, by the decrease of suspended solids in the filter effluent in September and October, 1935. Some concern was felt over the delay in unloading, but in November unloading started; there was moderate discharge in December, storage from January through April, heavy unloading in May, moderate in June and July, and again heavy unloading in September, when the filter rate was increased.

This record of a year's operation indicates that more or less continuous unloading may be expected, thus keeping the voids open and maintaining filter surfaces. Pooling was not observed either in winter or spring and the surface of the filter always had a clean appearance, although covered with a thin film of biological growth. A heavy growth of blue-green algae was noted on the surface in the late summer of 1936.

Quality of Effluent.—The final effluent had a B.O.D. varying from 12 to 44 p.p.m., averaging 24.3 p.p.m. The overall reduction varied from 69.0 to 85 per cent, averaging 74.9 per cent. These results are quite inferior to the results obtainable by activated sludge treatment. For several months in 1936 a small experimental activated sludge unit was operated at the West Side Treatment Works, handling the same Imhoff effluent that was applied to the trickling filter. A comparison of the effluents from the two experimental units is shown in Table VI.

Table VI.—*Comparison of Effluents*
Experimental Units
High Rate Trickling Filter and Activated Sludge
West Side Treatment Works

Month 1935–36	Operating Data			Analyses, Final Effluents							
				5-day B.O.D.				Suspended Solids			
		Act. Sludge		Parts per Million		Per Cent Reduction from Raw		Parts per Million		Per Cent Reduction from Raw	
	Filter M.G.A.D.	Aeration Period Hr.	Air, Cu. Ft. per Gal.	Filter Eff.	Act. Sl. Eff.	Filter Eff.	Act. Sl. Eff.	Filter Eff.	Act. Sl. Eff.	Filter Eff.	Act. Sl. Eff.
April	20.2	2.9	.72	23.5	10.2	75.3	89.3	30	16	75.7	87.0
May	20.2	2.9	.50	27.2	11.5	71.7	88.0	44	14	69.0	90.0
June	20.2	2.0	.47	25.5	15.1	69.0	81.6	30	8	70.0	92.0
July	20.2	2.0	.47	17.2	4.6	72.8	92.2	23	5	73. 8	93.7

Activated sludge discontinued July 16.

The 5-day B.O.D. of the filter effluent, settled, averaged 23.5, 27.2, 25.5 and 17.2 p.p.m. for the months April, May, June and July, 1936; the activated sludge effluent for the same months averaged 10.2, 11.5, 15.1 and 4.6 p.p.m. Likewise the suspended solids in the activated sludge effluent were far lower than those in the settled filter effluent (Table IV).

The activated sludge process was operated at very high rates, as shown by the short aeration periods of 2.9 down to 2.0 hours, and the air consumption was also low. With a clarified influent of such low concentration, these results indicate that the activated sludge process may also be operated at high rates, and still produce an excellent effluent.

The filter effluent, while not equal to an activated sludge effluent, still shows a substantial improvement over the Imhoff effluent, and it may be considered as possibly a little better than an effluent from chemical precipitation because of the appreciable amount of nitrate found in the filter effluent in summer. However, a reliable comparison could be made only if comparative experiments were made on the same influent.

The high-rate filter functions apparently as a biological flocculator, removing colloidal and soluble material in a manner analogous to that of a chemical precipitant. As such a flocculator, it is highly essential that the filter effluent be settled in a secondary settling tank. The period of 1.0 hour provided by the experimental tank for the first year of operation has now been increased to 1.5 hours.

B.O.D. Load Removed by Filter.—The removal of B.O.D. by a filter, as expressed in pounds per day per acre or per acre foot, is a reasonable measure of the efficiency of the filter, provided influents of equal or similar strength are compared. As the strength of the influent increases the removal by the filter also increases.

The B.O.D. removal by the high-rate filter is shown in column 6 of Table IV. The results show a variation from 2457 to 5150 lb. per acre per day, averaging 3763 for the year. This may not appear to be a particularly high rate when compared with others that have been reported, by Hatch (*Ohio Conference on Sewage Treatment*, 1931, p. 49), by Levine recently (Sewage Works Journal, **8**, 723, Sept., 1936), or by Hatfield for Decatur sewage when starch plant waste was present in 1928 (*S.W.J.*, **3**, 181, April, 1931), but the rate of 3760 lb. for the high-rate filter compares very favorably with Decatur data for 1930 and 1931 (*S.W.J.*, **6**, 499, May, 1934) when the filter influent was weaker and comparable to the West Side filter influent, as shown below:

The filter influent at Decatur had a B.O.D. of 75 to 81 p.p.m., and approximately 1650 lb. B.O.D. was removed, whereas the high-rate filter, with a much weaker influent (48 p.p.m.) removed 3760 lb. per acre per day. (On the acre-foot basis the difference is not so great, as the Decatur filter is only 6 ft. deep and the West Side filter is 8 ft. deep.)

A greater disparity in favor of the high-rate filter may be noted if

Decatur Filter
6 Ft. Deep

Year	Filter Rate M.G.A.D.	5-day B.O.D. P.P.M.		B.O.D. Removed	
		Filter Influent	Sec. Sett. Tank Eff.	P.P.M.	Lb. per Acre per Day
1930.....	3.33	75	15	60	1665
1931.....	3.00	81	16	65	1625

it is compared with an experimental .75 acre filter, 6 ft. deep, that was operated at the Calumet Treatment Works of the Sanitary District of Chicago for a number of years. The B.O.D. removals for this filter in 1925, 26 and 27 are shown in Table VII. With filter influents of

TABLE VII.—*Calumet Treatment Works*
B.O.D. Reduction by Trickling Filter
0.75 Acre, 6½ Ft. Deep

Year	Rate M.G.A.D.	5-day B.O.D. Parts per Million			Lb. per Acre per Day Removal
		Influent to Filter	Settled Effluent	Reduction	
1925.....	2.66	69	22	47	1043
1926.....	2.31	56	18	38	732
1927.....	2.43	55	17	38	770
Average.....					850

69, 56 and 55 p.p.m., respectively, the filter plus final settling tank removed 1043, 732 and 770 lb. per acre per day, averaging 850 lb. for the three years. This is a very low rate, due in part to the fact that biological filtration was inhibited somewhat by presence of industrial wastes (*Ind. Eng. Chem.*, **21**, 205, 1929), but the results give an indication of the low removals that have been obtained with filters dosed at low rates with very weak settled sewage.

Recirculation and Artificial Aeration.—Table I shows periods of re-circulation and Table II periods of artificial aeration. Re-circulation of such moderate volumes (13 to 15 per cent) of effluent seemed to be of no appreciable advantage with such a dilute sewage, so re-circulation was stopped in February, 1936.

Aeration was maintained by the blower from September through December, 1935, and again from May 15 through July, 1936, but the fan was shut off in August and September, 1936. July and August may be compared, as follows:

Month 1936	Aeration	Temp. Deg. F.		5-day B.O.D. P.P.M.				Diss. Ox. P.P.M. S.F.E.
		Sewage	Air	R.S.	I.E.	F.E.	S.F.E.	
July.....	Yes	74	78	63	34.7	40.7	17.2	5.2
August.....	No	78	76	79	28.1	18.5	13.3	4.5

These results do not indicate any advantage was obtained by aeration in July. The final effluent contained 5.7 p.p.m. dissolved oxygen in September, 1936, without aeration, and also 5.7 p.p.m. in September, 1935, with aeration.

It is difficult to find any justification for the cost of artificial aeration of this filter, while treating such a dilute sewage, in view of these results. Whether aeration is required for other more concentrated sewages must be determined elsewhere.

Filter Flies.—One of the most objectionable features of the trickling filter has been the plague of filter flies, *psychoda alternata.* It has been claimed that filter flies are not objectionable in filters operated at high rates, and this claim has appeared to be valid with reference to this small experimental filter. There were flies present below the surface almost continuously except in winter, but these flies did not come to the surface and escape so long as the surface was wet by continuous application of sewage. If the distributor was stopped for even a few hours, the flies came to the surface and escaped. However, the flies were relatively few as compared with the usual run of trickling filter. The small size of the filter must be taken into account—possibly a sizeable unit might not appear to be so free from the fly plague.

Winter Operation.—Operation of the distributor was not interfered with by winter conditions, during one of the coldest winters on record at Chicago. A galvanized-iron apron 3 ft. high was built around the periphery of the filter and this protected the distributor somewhat from the wind.

Cleaning of nozzles was necessary daily. The desirability of fine screening of filter influent, as at Baltimore, warrants further study.

Sludge.—Sludge was removed about twice a week from the secondary settling tank. The solids content was quite low, around 2 to 3 per cent, because of the withdrawal of water with solids from the hopper bottom. The volatile content, on the dry basis, was 61.9 per cent. The nitrogen content was 4.47 per cent. A casual Buchner test indicated that the sludge might filter readily on a vacuum filter, after treatment with ferric chloride.

Further Operation

The high-rate filter is still in operation, at a rate of 26.6 m.g.a.d., and it is hoped to operate it at this rate, or higher, for another year. Experimentation with trickling filters is a slow process, because of the

alternate loading and unloading, the marked seasonal variations, and the lag in adaptation to new conditions. Therefore it seems wisest not to make frequent changes in operating regime, but to establish some reasonable schedule of operation and to follow it through as long as time and money permit.

ACKNOWLEDGMENT

The experimental high-rate filter was started under the direction of Philip Harrington, Chief Engineer, and is being continued under William H. Trinkaus, Jr., Acting Chief Engineer. Langdon Pearse, Sanitary Engineer, has supervised operation, and L. M. Johnson, Engineer of Maintenance and Operation, has provided the operating personnel. The Public Works Administration has been represented by Joshua D'Esposito, as Resident Projects Engineer, and the P.W.A. Board of Review has also included Messrs. D. W. Mead, C. W. Kutz and W. B. Storey. The author wishes to express his thanks to T. L. Herrick, Asst. Civil Engineer, for assistance in compilation and summarization of results.

DETENTION OF LIQUIDS BEING MIXED IN CONTINUOUS FLOW TANKS

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The actual detention period in sedimentation tanks has been the object of numerous investigations in the past, but a similar analysis of the detention period of liquids in tanks being mixed mechanically or by diffused air has rarely been attempted. This is probably due to the complexity of such studies. There are, however, certain aspects of the problem which are comparatively simple and capable of rather exact mathematical analysis, a factor which places in the hands of those studying processes involving such tanks a rational approach to some of the problems which arise.

That mixing affects the detention of liquids under agitation in a continuous flow tank has been noted in the past; Calvert [1] states, in regard to activated sludge sewage treatment tanks, "When it (sludge) was added at the halfway point, 238 feet from the influent end, it soon worked back in reduced concentration nearly to the influent end." Kessener [2] has applied the term "relative short circuiting" to cover mixing in activated sludge aeration tanks and definitely attributes to this factor the shape of the curves obtained by the passage of chlorides through the tank.

Experimental Results

Prior to starting operation of the experimental activated sludge sewage treatment plant at this Station in August, 1932, tests on the detention period of the aeration tanks were made with uranin and with salt solutions, using in the former colorimetric comparison by dilutions and in the latter chloride analyses made according to Standard Methods of Water Analysis. The aeration tank consisted of a single rectangular wooden tank 6 ft. wide by 15 ft. long by 3.75 ft. deep with a water-tight baffle extending down the center. A three foot section of one end of this baffle was removable so that one-half of the tank could be used alone or both halves together, this latter arrangement giving in effect a single tank of identical cross-section, but twice the length of the half tank, with a reversal of the direction of flow at the mid-point. Aeration was furnished by a single row of diffuser tubes in the center of each side. The tests were made by filling the tank with Cincinnati tap water, then running in tap water from a constant head orifice box, together with sufficient concentrated salt solution to give a chloride concentration increase of approximately 100 p.p.m. in the inflowing water. Chloride analyses were made at half-hourly intervals on both the influent and effluent. The increase in chlorides in the effluent was computed as a decimal fraction of the chlorides added. The tests made similarly with uranin, although checking well during the early part of the run, were inaccurate when more concentrated solutions of the dye appeared in the tank effluent.

The results for both chlorides and uranin, using one-half of the tank, are shown in Fig. 1, while those obtained when both halves of the tank were used in series are shown in Fig. 2.

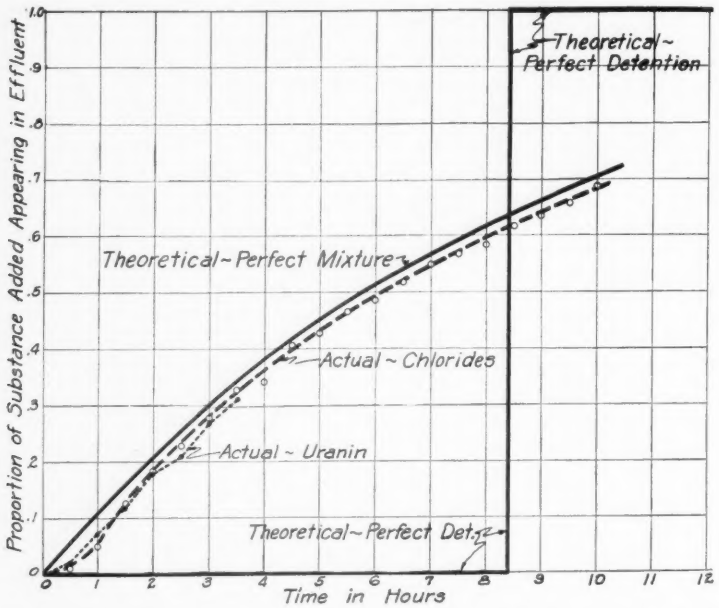

FIG. 1.—Effect of mixing on detention in experimental aeration tank, using one-half of tank with 2.5 gallons per minute flow.

Also shown in these figures are the lines for perfect detention and curves representing the theoretical proportion of chlorides appearing in the effluent, assuming a uniform mixture had been made constantly of the tank contents. This relationship is derived as follows:

Let X = total chlorides in the tank,
X_o = initial chlorides in tank due to chlorides in water,
t = time,
w = volume of influent per unit of time,
W = volume of tank,

$\frac{w}{W} = R$, the reciprocal of the displacement time,

RX_o = chlorides in tap water flow per unit of time.

Then assuming a unit amount of chlorides added per unit of time, the rate of increase in chlorides in the tank, dX/dt, is that added less the amount leaving the tank, or

$$(1) \qquad dX = (1 + RX_o)dt - RXdt$$

Integrating between X_o and X and o and t, and solving the resulting equation for RX,

$$RX = 1 + RX_o - e^{-Rt}$$

where e is the base of the Naperian system of logarithms.

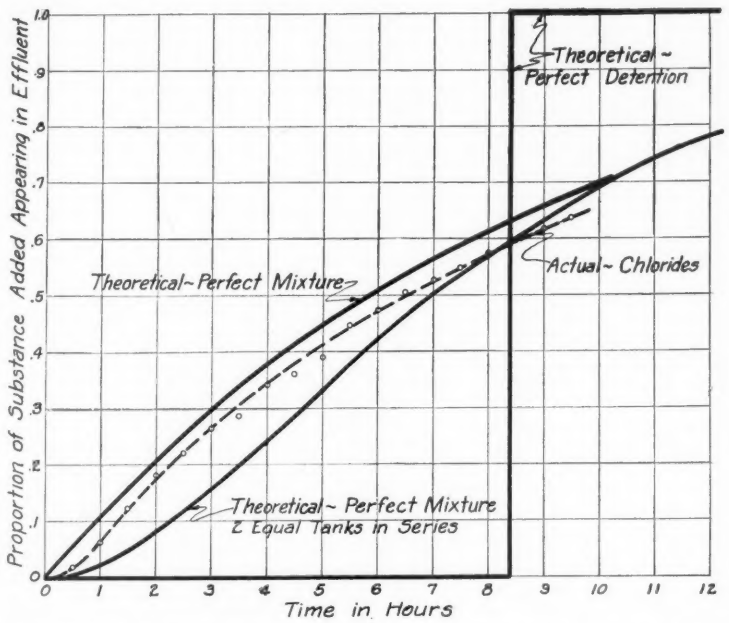

FIG. 2.—Effect of mixing on detention in experimental aeration tank, using both halves of tank with 5 gallons per minute flow.

If the initial chloride concentration is negligible or if a correction is made throughout for this normal chloride concentration of the tap water, the value for RX reduces to

$$RX = 1 - e^{-Rt} \tag{2}$$

or, correcting for the initial chlorides in both influent and effluent, $RX/1$, the ratio of effluent to influent chlorides is equal to $1 - e^{-Rt}$.

The close relationship between this curve, equation (2) plotted, as shown in Figs. 1 and 2, and the observed effluent chloride curves is at once apparent. The observed data for the half tank and for both halves together can be fitted quite well to this formulation, using $(t - .4)$ for t, or a time lag of slightly less than a half-hour in both cases.

Although conditions in the experimental tank, such as the amount of agitation and shortness of the tank, were quite favorable to rapid mixing of the influent with the tank contents, they are also favorable in most small activated sludge plants and it seems probable that in many small plants detention will follow reasonably well the above formulation. In large plants with long aeration tanks, it is obvious that this formulation would

not apply. Mixing in such tanks is probably, however, a major factor in their hydraulic behavior.

It is interesting to note the effect on the detention period of having two separate tanks in series. This is easily worked out for theoretically uniform and instantaneous mixing of the tank contents. Using the same terminology as before and leaving the flow the same, but dividing the single tank of W volume into two tanks of $W/2$ volume, the rate of change of total chloride in the second tank, denoted by subscript, dX_2/dt, is the amount leaving the first tank and entering the second tank, less that leaving the second tank, or

$$(3) \qquad dX_2 = 2RX_1dt - 2RX_2dt$$

$$\text{Since } X_1 = \frac{1 - e^{-2Rt}}{2R} \qquad \text{from (2)}$$

$$dX_2 = 1 - e^{-2Rt}dt - 2RX_2dt$$

which, integrated, gives for the proportion of chlorides appearing in the effluent, $2RX_2$,

$$(4) \qquad 2RX_2 = 1 - e^{-2Rt}(1 + 2Rt)$$

This curve is shown in Fig. 2. Repeated derivations by the method used in obtaining equation (4) result in a series and it is possible to give a general equation similar to (4) which will express for a group of N equal tanks in series the decimal fraction (NRX_n) of a substance added to the first tank at a uniform rate, which will appear after time t in the effluent of the last tank, under the conditions used in equation (2):

$$(5) \quad NRX_n = 1 - e^{-NRt}\left[1 + NRt + \frac{(NRt)^2}{\lfloor 2} + \frac{(NRt)^3}{\lfloor 3} \cdots + \frac{(NRt)^{N-1}}{\lfloor N-1}\right]$$

In the previously mentioned article of Kessener's [2] are given the curves obtained when "a large quantity of table salt in solution" was suddenly added to the first of a series of three equal sections of an activated sludge aeration tank of 144 cubic meters total capacity. A flow of 635 cu. ft. per hour of fresh water was maintained through the tank and the chlorides were determined at frequent intervals at eight sampling points, as numbered in the diagram in the upper right hand corner of Fig. 3.

The curves of chlorides for points 1 and 2 are omitted by Kessener from the original graph because the "dispersion of the salt solution was abnormal on account of the high specific gravity of the added salt." The chloride curves for points 4, 5 and 6 held closely together as did those for 7 and 8. Each of these sets of points has been averaged to give a single curve, in effect the average chloride concentration for a section of the tank. The samples from points 3, 6 and 8, however, being effluents from the preceding section are considered as samples from the preceding section. These average chloride curves for three sections are plotted in Fig. 3, and along with them are shown the comparable theoretical curves assuming that each section constantly contained a uniform mixture of all chlorides

in that section. The theoretical curves shown in Fig. 3 are from a different formulation than equation (5) since in this case an initially high chloride concentration is being diluted.

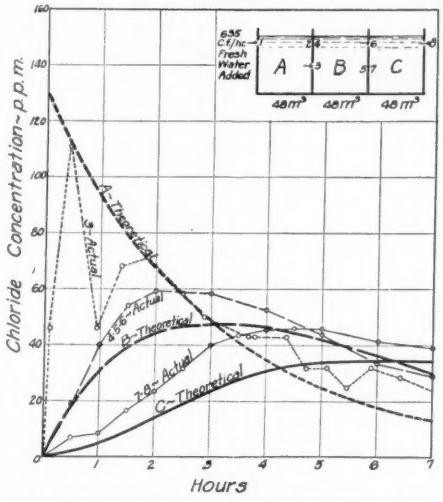

FIG. 3.—Distribution of flow through baffled activated sludge aeration tank—batch of salt in *A* section diluted by a constant flow of fresh water.

While the total amount of chloride added was not given by Kessener and it is, therefore, not possible to determine how far, vertically, the actual curves deviate from the theoretical, the general correspondence between the two sets of curves indicates that mixing is the major factor involved. In determining the relative vertical height of the theoretical curves shown in Fig. 3, the theoretical curve for section *A* was approximately fitted to the actual curve for section *A*. If the actual curve for section *A* was somewhat depressed by errors due to the specific gravity of the salt solution as Kessener suggested for the curves for points 1 and 2, the correspondence between the actual and theoretical curves in sections *B* and *C* would be better than that indicated in Fig. 3. This would seem to be the case since the deviations between actual and theoretical chlorides in sections *B* and *C* are both about the same, whereas an increasing deviation would be expected in section *C* if the true deviation between actual and theoretical in section *B* was as large as shown in Fig. 3.

APPLICATIONS

There are many possible applications for equation (5), one of which is in determining the residual substance in the effluent from a mixing tank under continuous flow when the velocity of the reaction occurring in the tank can be formulated. One of the simplest examples of this is the monomolecular reaction, which occurs frequently, the rate at which the reaction proceeds

being proportional to the amount (Y) of the original substance left

$$\frac{dY}{dt} = -K'Y$$

$$Y = Y_o e^{-K't} \tag{6}$$

where K' * is a velocity constant. Then if Y is the total amount of the substance in the liquor of a continuous flow tank being mixed, it will be changing by inflow, outflow and by the action assumed in (6). Using a unit of Y added per unit of time, and the same notation otherwise as in (1) and (2),

$$\frac{dY}{dt} = 1 - RY - K'Y = 1 - (R + K')Y \tag{7}$$ †

Integrating between limits o and Y for times o and t,

$$(R + K')Y = 1 - e^{-(R+K')t}$$

$$Y = \frac{1}{R + K'}(1 - e^{-(R+K')t})$$

$$RY = \frac{R}{R + K'}(1 - e^{-(R+K')t})$$

As a state of equilibrium is reached, t approaching infinity, the term $e^{-(R+K')t}$ approaches zero and $RY/1$, or the ratio of the substance in the effluent to that in the influent, becomes

$$RY = \frac{R}{R + K'} \tag{8}$$

A similar treatment for two equal tanks in series using the same terminology as in equations (3) and (7) gives for the ratio of the substance in the effluent of the second tank to that in the influent of the first, after a state of equilibrium has been reached,

$$2RY_2 = \left(\frac{2R}{2R + K'}\right)^2 \tag{9}$$

The rate of oxidation of sewage in the presence of activated sludge, although subject to wide variations, has been shown by McNamee,[3] to consist of two parts. One of these is an initial, rapid rate of oxidation of

* In the following discussion the symbols used to denote the velocity constant K will follow the terminology in Public Health Bulletin No. 173, "The Oxygen Demand of Polluted Waters" by E. J. Theriault. These are:

K = when the base is common logs (t is in days),
K_h = when the base is common logs (t is in hours) = 1/24 K,
K' = when the base is Naperian (t in days) = 2.303 K,
K_h' = when the base is Naperian (t in hours) = .0959 K.

† The writer is indebted to Lowell J. Reed for suggestions as to the treatment of this part.

the sewage which proceeds at an approximately monomolecular rate with a K value (common logarithms, t in days) of about 2.0. The second part consists of oxidation of the sludge itself, which proceeds substantially at a constant rate, approximately half of the total oxygen requirements being due to the sludge over a 4 to 8 hour period. From these considerations, and equations (8) and (9), a theoretical approach can be made to the relative dissolved oxygen requirements in each of a series of activated sludge tanks.

Taking into consideration only that part of the oxidation which varies at a monomolecular rate, with three tanks of total volume W and ratio of influent (sewage + return sludge) to total volume, $w/W = R$, then considering only the first tank, the ratio of influent to tank volume is $3R$ and the relative oxidation, o, taking place in the tank, from equation (8), is the unoxidized substance added, or a unit amount, less that leaving,

$$o_1 = 1 - \frac{3R}{3R + K'}$$

Similarly, from equations (8) and (9), the relative oxidation in the second tank would be

$$o_2 = \frac{3R}{3R + K'} - \left(\frac{3R}{3R + K'}\right)^2$$

and for the third tank

$$o_3 = \left(\frac{3R}{3R + K'}\right)^2 - \left(\frac{3R}{3R + K'}\right)^3$$

If R is assumed to be .167, corresponding to a 6-hour total detention period, and $K_h' = .192$, corresponding to McNamee's 2.0 value, for K, the variable portion of the oxidation (o) occurring in each of the three tanks would be, relatively,

$$o_1 = .277, \qquad o_2 = .200, \qquad \text{and} \qquad o_3 = .145$$

Since only half of the oxidation can be assumed as due to the sewage, .333 must be added to each of the oxidation ratios, giving for the relative total oxidation (O) in each tank:

$$O_1 = .610, \qquad O_2 = .533, \qquad O_3 = .478$$

and for the relative dissolved oxygen requirements based on that in the first tank: first tank 100 per cent; second tank 87½ per cent and third tank 78 per cent. This example illustrates a rational approach to the problem of relative oxidation in a series of activated sludge tanks.

The foregoing example is based on oxidation rates for sewage plus activated sludge. The removal of organic matter from the substrate of sludge-sewage mixtures is a much more rapid process. The reaction velocities concerned have not been definitely determined. Until these have been worked out, it will not be possible to apply this method of

analysis to the important problem of the total purification in activated sludge aeration tanks.

Another possible application of equation (8) would be in sludge digestion. Fair and Moore [4] have given a two-stage formulation of the course of digestion based on gas production in batch experiments seeded with digested sludge. The last stage follows a monomolecular curve while the first stage "can be represented satisfactorily by an equation defining a constant rate of increase." The first stage is in effect a lag which, according to data published by Keefer and Kratz,[5] would almost disappear when the sludge to be digested is seeded with an equal quantity of well digested sludge. Since the mass of seeding in a sludge digestion tank is much greater than the sludge added, it does not seem unreasonable to assume for all practical purposes that the lag will disappear under seeding conditions found in a normal sludge digestion tank. The constant K which Fair and Moore give for the second stage of their sludge digestion formulation, similar to equation (6), when common logarithms are used and t is in days, is .073. This compares favorably with the value .06 obtained from a rough plot of data from Keefer and Kratz, particularly since the experiments of Fair and Moore were made at 37° C. while those by Keefer and Kratz were at 28° C. With a rate of digestion following a monomolecular equation, equation (8) could be applied and should, in digestion tanks which are mixed, give a rational basis for analysis of some of the problems in sludge digestion. For example, under conditions of continuous addition and removal of sludge and thorough mixing of the tank contents, the capacity of tank required to insure that gasification of the drawn sludge was 90 per cent complete would be, from equation (8), using $K = .073$ ($K' = .169$),

$$\frac{RY}{1} = \frac{R}{R + .169} = .1 \qquad R = .0187$$

or 53.5 days storage. If Imhoff's [6] figures for production of sludge, 1/4 gallon of 95 per cent moisture sludge per capita per day, are taken, the capacity necessary to give 53.5 days storage would be 1.85 cubic feet per capita.

The foregoing examples are given only to demonstrate certain uses to which the theories developed in the first part of the paper may be applied. It is felt, however, that these theories hold distinct promise as a rational approach to some problems, the solution of which, heretofore, has been almost entirely empirical.

Conclusion

Detention in short mixing tanks used in continuous flow follows reasonably well the theoretical curve based on the assumption that the contents of the tank are at all times completely mixed.

A mathematical treatment of the course of a monomolecular reaction occurring in such tanks is presented and certain possible applications to the field of sewage treatment are discussed.

The use of the formulations presented, as a rational approach to these and similar problems, is proposed.

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Plant Operation

COMPARISON OF SEWAGE PURIFICATION BY COMPRESSED AIR AND MECHANICALLY AERATED ACTIVATED SLUDGE *

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II. Comparative Costs

In the first paper [1] of this series a comparison between compressed air of the spiral circulation type and mechanical surface aeration of the brush type was presented with respect to degree of purification and settling characteristics of the activated sludge floc. A comparison of the two types of aeration is obviously incomplete unless the relative operating costs are taken into consideration. The purpose of this paper is to present comparative cost data for the two types of aeration.

Method of Investigation

The principal items involved in comparing costs of two types of aeration systems are: power consumption, operation attendance, and capital cost.

Operation attendance and capital cost can be directly compared on the basis of plant capacity. Power consumption, however, must be related to common indices of work performed. This, in the activated sludge process, may be first, a general index of degree of purification accomplished and second, more specifically, an index showing the relation of power consumption to dissolved oxygen concentration and circulation velocities of the liquor in the aerators. In this investigation, comparisons of power consumptions of the two types of aeration are made with respect to (1) circulation velocities, (2) dissolved oxygen in the aerator liquor, and (3) overall purification.

The procedure used to obtain these comparative cost estimates was as follows:

1. Power consumption was obtained by direct measurements of power consumed by each aerator.

2. Distribution of dissolved oxygen was investigated by tests on samples from five points in each aerator at the beginning, middle and end of the tanks. The cross-sectional distribution of these points was: middle top, middle center, middle bottom and half-way down at each side of the tank.

3. Purification performance was based upon the common indices of B.O.D. reduction, NH_3–N reduction, NO_2 and NO_3–N formation and suspended solids reduction.

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4. Circulation velocities were obtained by direct measurement with a Gurley velocity gauge. These velocities were taken on a vertical line in the middle of the tank at depths of 0.25, 1, 2, 4, 6, 8, 10, 12, and 13.5 feet below the liquid surface.

5. Operation attendance was estimated by actual plant experience.

6. Capital costs were obtained from actual construction costs.

Results

Tables I and II and Fig. 1 show the correlation between tank velocities and power consumption for each type of aeration. The velocity

Table I.—*Tank Velocities with Varying Power Consumption*

Depth Below Surface, Feet	Velocity of Circulation in Feet per Second					
	Air			Brushes		
	4.2 H.P.	7.8 H.P.	11.5 H.P.	4.0 H.P.	7.0 H.P.	10 H.P.
0.25	1.47	1.91	1.90	2.49	2.60	4.05
1.0	0.99	1.48	1.43	1.05	1.13	0.60
2.0	0.79	1.04	1.19	0.73	0.90	0.40
4.0	0.42	0.59	0.62	0.40	0.51	0.10
6.0	0.22	0.25	0.30	0.10	0.10	0.33
8.0	0.30	0.37	0.37	0.21	0.16	0.43
10.0	0.54	0.84	0.92	0.70	0.65	0.60
12.0	0.95	1.25	1.30	1.20	1.20	1.05
13.5	1.15	1.50	1.60	1.43	1.60	1.43
Average	0.76	1.02	1.07	0.92	0.98	0.98

Table II.—*Comparison of Tank Velocities per Unit of Power*

Depth Below Surface, Feet	Velocity per H.P. Consumed					
	4.0 to 4.2 H.P.		7.0 to 7.8 H.P.		10.0 to 11.5 H.P.	
	Air	Brushes	Air	Brushes	Air	Brushes
0.25	.35	.62	.24	.39	.16	.40
1.0	.23	.26	.19	.16	.12	.06
2.0	.19	.18	.13	.13	.10	.04
4.0	.10	.10	.07	.07	.05	.01
6.0	.05	.02	.03	.01	.02	.03
8.0	.07	.05	.05	.02	.03	.04
10.0	.13	.18	.11	.09	.18	.06
12.0	.22	.30	.16	.17	.11	.10
13.5	.27	.36	.19	.23	.14	.14
Average	.18	.23	.13	.14	.09	.09

values given are the average of all readings taken at each point. The average results were compiled from ten individual velocity-meter readings for each point and for each power reading given.

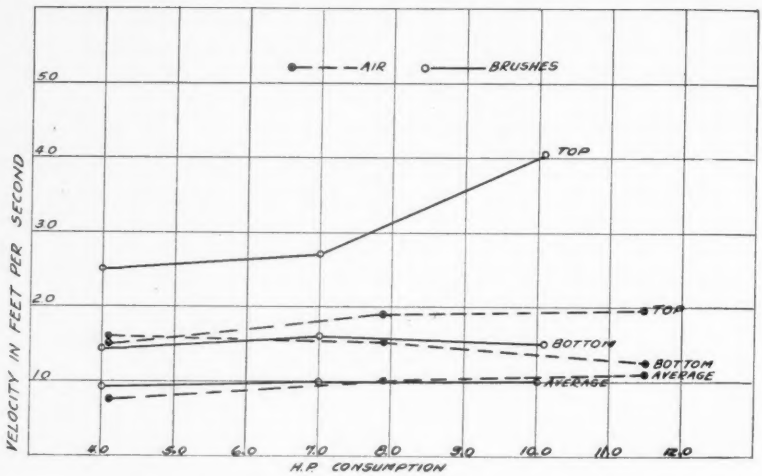

FIG. 1.—Velocities in tanks with varying power consumption.

TABLE III.—*Distribution of Dissolved Oxygen at Points No. 1, No. 2 and No. 3*

Sampling Point	Air, 11.5 H.P.			Brushes, 10.0 H.P.		
	Point 1	2	3	Point 1	2	3
	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.
1 A	0.4	0.9	3.0	0.2	3.1	4.5
1 B	0.0	0.8	1.7	0.2	3.1	4.5
1 C	0.1	1.3	3.0	0.2	3.2	4.3
1 D	0.3	1.4	3.0	0.2	3.2	4.4
1 E	0.5	1.4	3.1	0.5	3.1	4.4
Average	0.26	1.16	2.74	0.26	3.14	4.42

TABLE IV.—*Residual Dissolved Oxygen per Unit Maximum Power Consumption 10 to 11.5 H.P.*

Sampling Point	Point 1		Point 2		Point 3	
	Air	Brushes	Air	Brushes	Air	Brushes
	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.
1 A	.04	.02	.08	.31	.26	.45
1 B	.0	.02	.07	.31	.15	.45
1 C	.01	.02	.11	.32	.26	.43
1 D	.02	.02	.12	.32	.22	.44
1 E	.0	.05	.12	.31	.25	.44
Average	.014	.026	.100	.314	.228	.442

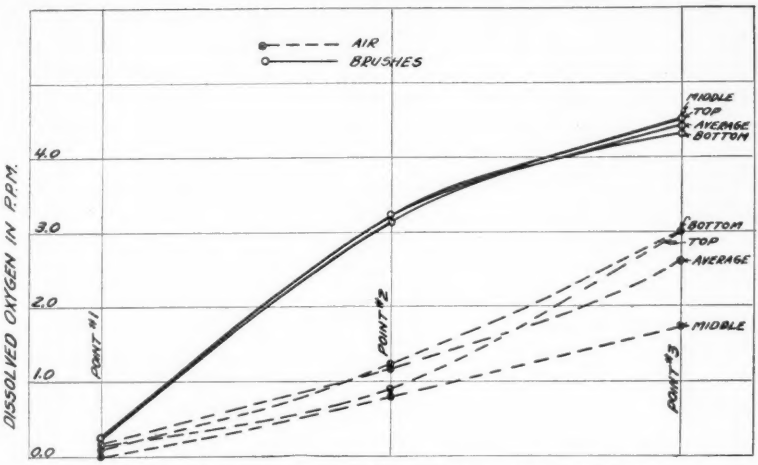

FIG. 2.—Progressive dissolved oxygen through the aerators.

Tables III and IV and Fig. 2 give the dissolved oxygen content of the mixed liquor in the aerators at points 1, 2, and 3, in relation to power consumption. The dissolved oxygen tests were run on the supernatant liquor after five minutes settling and the results are averages of five individual tests at each point shown.

DISCUSSION

Distribution of Circulation Velocities.—The circulation characteristics of the two aerators should be analyzed from two viewpoints: first, with respect to the average velocities, and second, the distribution of velocities. Of these two, the second is of the major significance.

In Tables I and II, showing circulation velocities for equal power consumption, it appears that the relation between average velocities in the aerators differed with varying speed and power consumption. The greatest average difference existed at low speeds and low power consumption. This difference decreased with increased speeds of circulation. The actual average difference existing at any speed was, however, of no practical significance. The greatest difference shown amounted to only 0.05 ft. per sec. per unit of power consumed, or 0.16 ft. per sec. for the lowest practical speed. For the higher speeds even this small difference was eliminated.

However, a major divergence existed between the two aerators in the distribution of velocities over the tank cross-sections. For equal power consumptions, the surface velocity of the brush aerator was 1.77 times as high as the surface velocity with air at lower speeds of circulation, and this ratio increased to 2.5 at the higher velocities. The bottom velocities were also higher for the brushes, but the divergence was in an opposite direction. The maximum difference here occurred at the lowest speed instead of at the highest. The actual difference was also less, amounting to a maximum of only 1.28 times as much velocity

per horsepower for the brushes as against a maximum of 2.5 times in the case of surface velocities.

In the middle section, between 4 and 8 feet, the relationship was less uniform. Generally speaking, the compressed air gave highest average circulation velocities in this section for all equivalent power consumptions. On the two outer thirds this relationship did not hold. For the lowest power consumption the velocities were highest for the brushes, but for higher power consumption the relationship was reversed. Accordingly, it would appear that although the general circulation characteristics are the same, the compressed air tends to give more uniform distribution of velocities than the brushes. From the practical standpoint, however, it would appear that the differences, with the exception of the top velocities, were too small to be significant. This would mean that distribution of activated solids throughout the mass and distribution of dissolved oxygen by mixing should be nearly equal for the two types of aeration. The decidedly higher surface velocity created by the brushes, however, would indicate that a major difference in performance might arise as a result of increased absorption of atmospheric oxygen by the brushes at the water level surface. This would be confirmed by a study of dissolved oxygen distribution in the aerators coincident with the study of circulation velocities.

Distribution of Dissolved Oxygen.—From the viewpoint of dissolved oxygen and its distribution in the aerators, results with the brushes and porous tubes are compared in Tables III and IV and in Fig. 2. These results show some decided differences in performance between the two types of aeration. In both total quantity of D.O. and uniformity of distribution the brushes surpassed the compressed air for equal power consumption.

In aerator B, with brushes, the total quantity of D.O. near the aerator inlet was only slightly higher than that at a similar point in tank C. This might be expected as the sewage had just been mixed with the return sludge, with comparatively high B.O.D., and the time of aeration was too short to show significant differences. At more advanced sections of the aerator, however, the residual dissolved oxygen in the brush aerator liquor increased to a maximum of nearly 100 per cent greater than in the compressed air tank, with the same power consumption.

The distribution of the dissolved oxygen in the brush aerator liquid was also much more uniform at all points of the tank cross-section. No tendency for "core" formation was apparent at any position in the length of the tank. In contrast to this, the dissolved oxygen in the compressed air tank varied at different cross-sectional points, with a decided tendency for "core" formation at the center of the tank. The greatest deviation in uniformity in the air tank occurred at point 3, which is the outlet end of the tank, and amounted to approximately 77 per cent difference between the dissolved oxygen content at the center and the maximum amount in the outer layer of the circulating liquor.

It seems apparent from the data and the circulation studies previously discussed, that the quantity of dissolved oxygen in the aerators for the same power consumption is closely related to the surface circulation velocity and is more a function of the dissolved oxygen absorbed at the surface than of the oxygen introduced under water by compressed air. This is further confirmed by relating the data of these two studies at points 2 and 3, where the B.O.D. of return sludge has been overcome. The ratio of the average dissolved oxygen at these two points in the brush aerators to the average dissolved oxygen similarly obtained in the compressed air tank was 2.15. The ratio of surface velocity in the same order was 2.13 or almost exactly the same as the D.O. ratios. The average velocities for the two aerators, however, are practically identical.

It appears, therefore, that with respect to the amount of D.O. supplied to the aerators, the brushes are superior to compressed air, for equal power consumption, because of the larger quantity of atmospheric oxygen absorbed at the surface as a result of the higher velocity induced by the brushes. The distribution of dissolved oxygen is also much more uniform with brush aeration, in contrast to the tendency for core formation in the compressed air unit.

Power Consumed With Respect to Purification Index.—Coincident with the comparison of purification performance of the two aerators discussed in the preceding paper of this series, data were obtained on power consumption during the same period. The degree of purification was stated to be approximately equal for the two aerators. The question of economy of operation with respect to power consumption resolves itself, therefore, into a direct comparison of power used during that period of study. The average power consumptions, for the period upon which the results of purification were based, were as follows:

	Actual H.P. Consumed per Day	H.P. per Million Gallons Treated
Average for year—brushes	6.5	20.8
Average of year—air	8.4	26.2

These figures serve for purposes of comparison but do not correspond to power consumption for all conditions of operation. For instance, the D.O. required for the aerators is dependent upon, among other factors, the concentration of solids carried in the aeration tanks. These solids may be high or low as required by the degree of purification and the strength of the incoming sewage. The foregoing, figures were based upon a very highly purified effluent, which, except in very unusual instances would not be required. To find the comparison at what might be considered the minimum degree of purification desirable in this installation, additional data were obtained under conditions of operation where the activated sludge solids were carried in minimum amounts and the dissolved oxygen was maintained in just sufficient quantity to furnish the minimum degree of purification desired. On this basis the average power consumption was as follows:

	Actual H.P. Consumed per Day	H.P. per Million Gallons Treated
Average for year—brushes	4.1	12.8
Average for year—air	5.0	15.7

These figures show that the actual power required may vary over a wide range for both types of aeration, depending on the results which are desired. They also show that, from the operating standpoint, the brush type of aeration is less expensive than the compressed air for all degrees of purification required. For the minimum degree of purification the brushes required 18.4 per cent less power than the compressed air for equal overall purification results. For the higher degree of purification the saving was somewhat higher, amounting to 22.5 per cent. The average was 20.4 per cent. It should be observed that in both cases the residual dissolved oxygen content in the brush aerated tank was higher than that in the compressed air tank. For the minimum degree of purification the brush aerators maintained 1.66 p.p.m. D.O., 24 per cent more than in the compressed air tank. For the higher degree of purification, the dissolved oxygen in the brush aerator was 3.44 p.p.m. or 30 per cent more than in the compressed air tank. This indicates that if residual oxygen were maintained equal, the savings by brushes would be even greater than the average of 20.4 per cent indicated by the figures given on the basis of comparative purification.

Operating Flexibility and Attention Required.—An evaluation of operating flexibility and operation attention requirements is based largely upon operation experience.

The requirements for operation flexibility are confined mainly to ease of adjustment to changing conditions and emergencies which may arise. Any such differences between the two types of aeration can be eliminated by proper foresight and correspondingly proper design for each type of aeration. One of the main requirements for operation flexibility can be met if provisions are made to cut out, remove, or repair small sections of the aeration devices in each tank so that purification results will not be seriously affected. This can be easily accomplished with each type of apparatus, since the brushes can be economically installed in removable lengths as short as 10 feet or under, and each porous tube section is only 5 feet long. Facilities can be provided for spare part replacement in each case. A second main requirement of operation flexibility is the ability to vary the quantity of air supplied to the tanks under changing conditions of sewage strength, quantity and concentration of activated sludge, etc. This also can be accomplished by variably speeded apparatus for the brushes and by variable or duplicate air compressor units for the diffused air.

Dependability of the two types of apparatus is also a factor. Experience has shown that if spare parts are provided for the brush driving mechanism, the dependability of each type is approximately equal.

The operating attention is confined principally in the case of brushes

to greasing brush hanger bearings and driving mechanism and to proper checking and alignment of shaft bearings. Corresponding to these requirements, the compressed air facilities demand frequent flushing of the porous tubes by water under pressure or by chlorine solution. At less frequent intervals the tubes must be removed for more drastic cleaning. From the standpoint of operation attention the brushes require more frequent but less laborious attention than the air tubes. In terms of total labor expended throughout an operating year, it has been found that total labor required in operating attendance is about equal for each type of aeration.

Comparison of Capital Cost.—In view of the similar design of structures used in this investigation and of the similarity of purification ability, the capital cost comparison can be shown by the difference between the cost of the mechanism required for the two types of aeration.

The construction cost of brush mechanism complete at this plant in 1932 was $6,150 per million gallons of sewage treated, and the cost of the compressed air mechanism was $5,500. On the basis of total capital cost of plant this difference amounts to only 0.75 per cent per million gallons.

Conclusions

The foregoing results indicate that with respect to aerator construction and operation, mechanical aeration by means of brushes is more economical than spiral circulation by compressed air. Capital cost of aerator construction and labor attendance are approximately equal but lesser operating cost, with respect to purification performance, dissolved oxygen supplied to the aerators, and circulation velocities, is shown by the brushes. In addition distribution of dissolved oxygen was more uniform in the tank with the brush type of aeration, and circulation velocities were higher at both top and bottom of the brush tank, with the same power consumption.

Previous results on the relative purification and sludge settling characteristics [1] show advantages in favor of the compressed air principally on account of the denser sludge floc, but the investigations on operating costs distinctly favor the mechanical aeration by means of brushes. This means that the relative value of each type of aeration is controlled by specific circumstances of application. In general, where increased capital costs are more of a consideration than continuous operating cost, or where the greater capitalized cost of initial construction of the brush type of aeration, due to less dense sludge floc, is greater than the saving in power operating costs effected thereby, the compressed air type of aeration is the better, but where these capitalized costs are of less importance or of less value than the operating costs the mechanical aeration of the brush type is superior.

Summary

Investigations were conducted on an activated sludge plant under practical operating conditions to determine the relative merits of

mechanical aeration with brushes and spiral-flow compressed air, with respect to comparative costs of the two systems.

The indices used for comparison were power consumption, purification, dissolved oxygen in quantity and distribution, circulation velocities, labor attendance, and capital costs. The investigations were conducted under identical conditions of structural design and operating conditions.

The results showed that:

(1) Power consumed by the brush type of mechanical aeration was 18 to 22 per cent less than by compressed air, for equal degree of purification.

(2) Distribution of dissolved oxygen throughout the liquid mass was more uniform with the brushes.

(3) Average circulation velocities were approximately equal for each type of aeration but the brushes gave much greater velocities at the surface of the liquid and bottom of the aeration tanks than compressed air.

(4) Capital costs and costs of operation attendance were approximately equal for each type.

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SEWER FLUSHING PREVENTS BULKING OF ACTIVATED SLUDGE AT FLORA, ILLINOIS

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Foreword

Bulking activated sludge, with visible sphaerotilus growths in the final tank, was a characteristic condition during hot weather operation in the summer of 1935 and the spring of 1936, at the Flora, Illinois, sewage treatment works. The application of various reported intra-plant methods for the prevention of bulking proved to be ineffective.

Investigation of the composition of the raw sewage and the conditions of the sewer system revealed large deposits of sludge in a stage of alkaline digestion, having B.O.D.'s to 1500 p.p.m. Subsequently, flushing the laterals resulted in the maintenance of a continually excellent activated sludge yielding B.O.D. reductions to 98 per cent on a raw sewage strength of 570 p.p.m. B.O.D.

Low Water Consumption Causes High Strength Sewage

The City of Flora has a population of 4393 people and is located in Southern Illinois just 100 miles east of St. Louis.

While the city has a completely modern and adequate water supply and treatment plant, the average water consumption in the city still remains under 40 gal. per capita per day.

Prior to 1929 the city water supply was drawn from a few low-capacity wells. This supply was so limited that it was regarded as a luxury. For long periods each summer the use of water was limited to the most important household uses. Because of this long water shortage the people still have low water consumption fixtures and are habitually "water-savers."

Prior to 1934 the sewage of Flora was discharged from an existing septic tank into a creek. The septic tank was of small capacity and was overloaded. The creek was almost completely dry during the greater part of each year with the exception of the sewage flow. The condition of this creek was so bad that the city proceeded with plans for a modern sewage disposal plant.

Description of Activated Sludge Plant

The activated sludge process for sewage treatment was employed at Flora to obtain a high quality effluent and to avoid pumping the raw sewage. The difference in elevation between the interceptor and the flood level of the creek necessitated a plant of low head-loss.

The plant was designed for a total sewage flow of 600,000 gallons per day with an estimated sewage strength of 200 to 250 p.p.m. B.O.D. At the time the plant was designed it was thought that the plentiful

water supply from the new source would induce the inhabitants to increase their water consumption. The present low rates of sewage flow indicate that this assumption has not been realized.

The present plant consists of two 10-inch comminutors, placed in the raw sewage channel; a primary settling tank, equipped with a spiral sludge collecting mechanism; four Chicago Mechanical Aerators; a secondary settling tank, also equipped with a spiral sludge collecting mechanism; an unheated, open sludge digestion tank; sludge drying beds; and, a control building. Return activated sludge pumps, raw sludge pumps, an electrical control panelboard, and a small laboratory are housed in the control building.

The comminutors eliminate the necessity for screening and screenings disposal. Coarse sewage matter cut to sizes small enough to pass through the ¼-inch drum slots, settles out in the primary tank and is pumped to the digester with the primary sludge. The primary settling tank, the aeration tanks, and the final settling tank, all hexagonal in plan, are nested together (Fig. 1). The substructure of the control

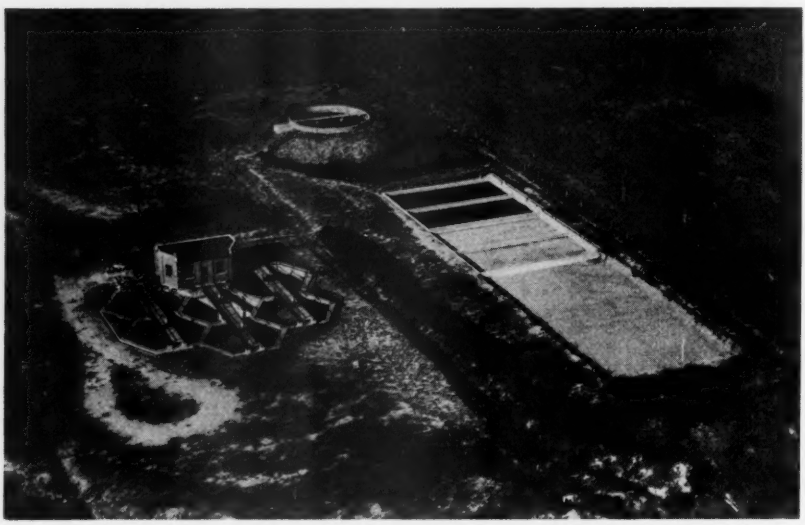


FIG. 1.—Airplane view of the Flora, Illinois, sewage treatment works (Aero-Graphic Corp. Photo).

building is a half-hexagon, located between the primary and final tanks. The primary and final tanks have capacities of 50,000 gallons each, affording two-hour detention periods on the design flow. The aeration tanks, having slightly sloping bottoms, hold 48,000 gallons each, affording a detention period of six hours for the entire battery on the design flow plus 25 per cent return sludge. The digestion tank has a holding capacity of 136,000 gallons amounting to 4.1 cubic feet per capita for the present population.

The consulting engineer for the plant design was A. C. Stanfield of Pana, Illinois.

Initial Operation Without Primary Sedimentation

The plant was put in operation late in November, 1934. The scheme of operation at this time eliminated the primary settling tank, the raw sewage being discharged into the first aeration tank. An activated sludge was quickly formed, resulting in the production of a satisfactory effluent. During the following three months, it was observed that increased flows, due to rain, washed sludge and inorganic matter from the sewers directly into the aeration tanks. These concentrated charges of organic matter ultimately destroyed the activated sludge. In March, 1935, the primary tank was put into service, after it had been demonstrated that primary sedimentation would eliminate destruction of the activated sludge during periods of increased sewage flow.

A good activated sludge and a satisfactory effluent was continually maintained from the time the primary tank was put into service until the middle of May, 1935.

Sludge Bulks in Hot Weather

Coincident with the start of hot weather the sludge started bulking. Repeated wasting of the sludge and efforts to build up a new sludge were of no avail. Microscopic observations of the sludge indicated that it consisted almost entirely of filamentous organisms. In the final tank, growths of these filamentous organisms formed into ropes one to two feet long and hung from the metal effluent launder.

In August, 1935, operation of the plant was taken over by the Chicago Pump Company and a complete study of the problem was immediately undertaken.

The sewage flow averaged 135,000 g.p.d. with raw sewage strength between 300 and 750 p.p.m. B.O.D.

One unit was employed in September to serve as a basis for experimentation to solve the problem of bulking. Concentrating all of the flow in one aeration tank yielded over eight hours detention on the average dry-weather sewage flow.

After several days of operation an extremely light, flocculent sludge was developed, not at all characteristic of a typical activated sludge. Continuous tests indicated the presence of dissolved oxygen in the aeration liquor at all times. Microscopic observations of the sludge revealed heavy filamentous growths. The only protozoa visible were a few vorticella. The sludge would not settle in the clarifier or in a 1000 cc. graduate. As before, ropes of this filamentous material formed in the final tank, growing to lengths of three feet.

The plant was then by-passed and the primary tank, aeration tank, and final tank were emptied, cleaned, and washed with a strong copper sulphate solution. As soon as the plant was again put into operation, the filamentous growths reappeared and the sludge continually bulked.

Following this, effluent equivalent to 125 per cent of the raw sewage flow was returned by the activated sludge pump. This diluted the raw sewage but had no effect in reducing the filamentous growths.

The addition of lime in solution to the primary effluent was employed for several days. A pH over 8.0 was maintained in the aeration mix by the lime. The pH of the aeration mix before the lime was added varied between 7 and 7.5. Liming the influent to the aerators produced a marked improvement in the settling rate of the sludge. However, there was not any improvement in the quality of the sludge. As soon as the liming ceased the sludge bulked again to its former volume.

Re-aeration of the return sludge was next tried. Two of the empty aerators were used for re-aeration. Various detention periods, in these tanks, up to 100 hours failed to improve the quality of the sludge, or to eliminate any of the filamentous growths. Dissolved oxygen in the re-aeration tanks was maintained continuously.

The B.O.D. values of the raw sewage composites were so varied and so strong that it was decided to make a survey of the sewerage system, with three objects in view:

First, to locate, if possible, some point in the system where filamentous growths were developing in the sewers. This was thought a possibility because on several occasions grab samples of the raw sewage were collected in sterile bottles and aerated for several days. In every case filamentous growths developed as the most abundant and almost the only type of life after one or two days of aeration.

Second, to determine if sugar wastes were entering the system in large quantities, since reports in the literature linked filamentous growths in activated sludge with wastes of high sugar content.

Third, to determine what section of the city and, if possible, what exact building in the city was responsible for the extremely high strength of the raw sewage. The studies were carried on during the period the re-aeration experiments were in progress.

The skeleton map of the City of Flora, Fig. 2, shows all of the principal sewers of the city, the points and time at which the samples were taken and the strength reported in p.p.m. B.O.D. These samples were also analyzed for sugar. No sugar was ever found except in the sample from the sewer directly downstream from the Armour and Company cheese factory. There the flow was so low that there would be no appreciable effect on the strength of the total sewage from the city.

The following information regarding the wastes from the Armour Cheese Factory was obtained by tests and observations made at various times by sanitary engineers of the Illinois Department of Health and of the Chicago Pump Company.

The product of the Armour plant is cream cheese. The plant capacity is 60,000 pounds of milk per day. The maximum received to January 1935, was 45,000 pounds per day. The average receipts are from 15,000 to 20,000 pounds per day.

All whey produced is separated before being given to farmers supplying milk. Whey has been temporarily discharged to the sewer when the whey pumps have become inoperative due to electric power failure.

This company has been requested by the Illinois State Department of Health either to provide a gasoline engine to operate the whey

pumps during electric power failure, or to install a 10,000 gallon ground storage tank for the whey.

Wastes ordinarily discharged to the sewer comprises floor and equipment wash water, condensing water and sanitary sewage. The total volume of discharge averages about 11,000 g.p.d.

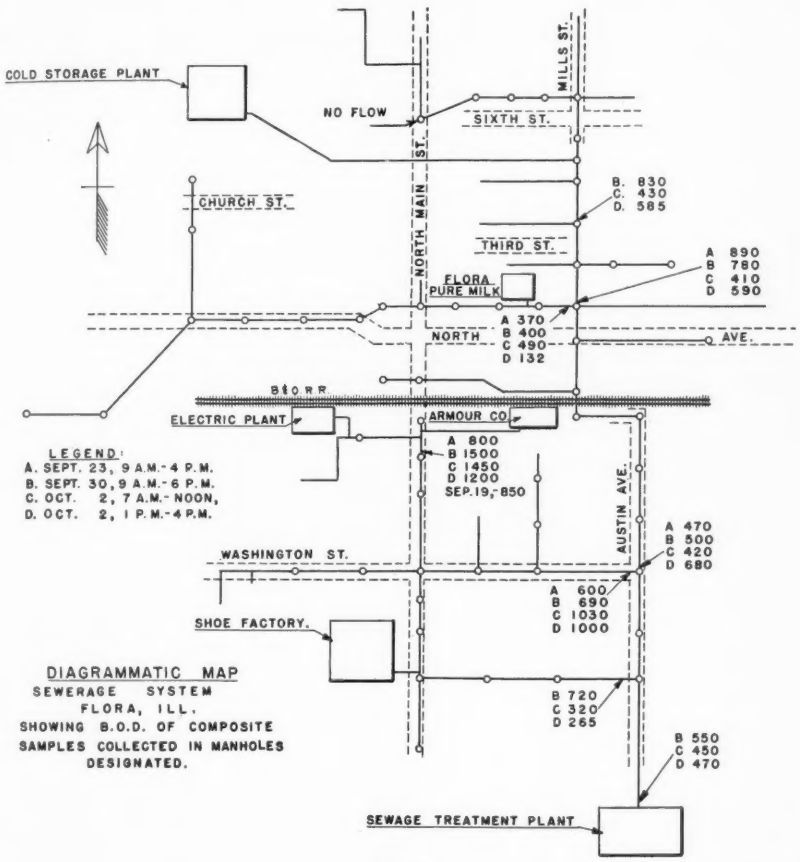


FIG. 2.

No indications of whey being discharged into the sewers during 1935 was found by Harold Coil, Supt. of Water and Sewage Treatment for Flora, during frequent inspections.

Flow tests were made in the sewer, directly downstream from the Armour plant, on October 8th, 1935. A 90° "V" notch weir was installed in the manhole nearest the Armour plant.

The flow at this manhole comes from the Armour plant; the Municipal Light and Power Company; and from three or four small cottages. The Light and Power Company contributes flow only from one toilet

fixture and lavatory and from the water softener back-wash, which occurs twice daily.

Readings of the head on the weir were equivalent to the following rates of flow:

		G.P.M.	
October 8,	1:30 P.M.	12	
	2:30 P.M.	6	
October 9,	7:30 A.M.	45	just after filter back washing
	8:30	4	No sugar
	9:30	4	No sugar
	10:30	4	No test
	11:30	7	Less than 100 p.p.m. sugar
	1:00 P.M.	22	Less than 100 p.p.m. sugar
	2:00	10	700 p.p.m. sugar
	3:00	4	200 p.p.m. sugar
	4:00	35	200 p.p.m. sugar
	5:00	12.5	

Armour and Company opened at 7 A.M. and closed at 5 P.M. The B.O.D. of the composite of October 9th samples (samples proportional to flow) was 480 p.p.m.

No filamentous growths were ever located in any of the slime scraped from the side of the sewers at any of the sampling points. The general distribution of the high strength samples eliminate the possibility of a single source.

Following the failure of the re-aeration experiments, chlorination of the return sludge was tried.

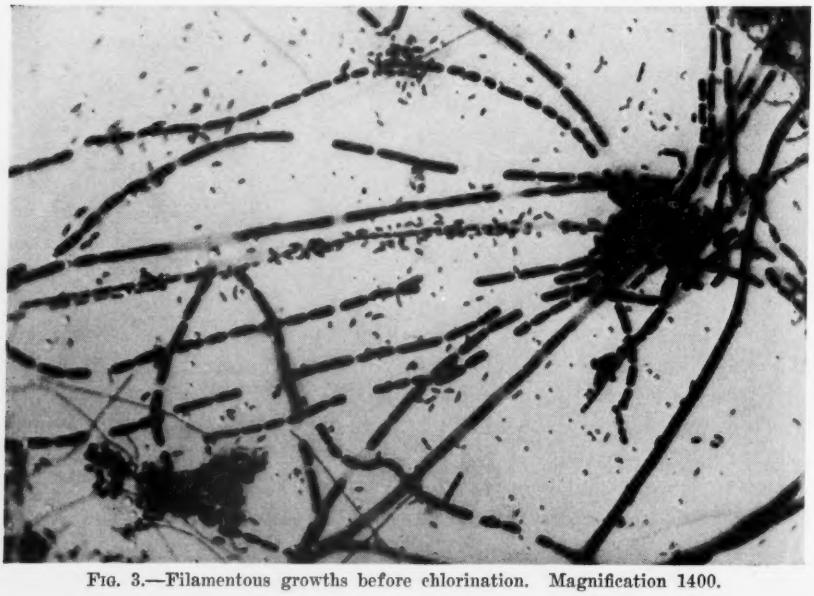


FIG. 3.—Filamentous growths before chlorination. Magnification 1400.

Chlorination of the return sludge was reported by E. E. Smith of Lima, Ohio (*Water Works and Sewerage,* October, 1935) as a control for bulking sludge. A chlorinator was set up at the Flora plant and the return sludge was chlorinated with dosages from 4 to 8 p.p.m. for six weeks. Figure 3 is a photograph of a stained plating of the return activated sludge organisms before chlorination. Figure 4 is a photo-

FIG. 4.—Filamentous growths after chlorination. Magnification 1400.

graph of a stained plating made after chlorination of the return activated sludge. The bulking characteristic continued throughout the entire period of chlorination. As shown in Figures 3 and 4 chlorination had very little effect on elimination of the filamentous organisms in the activated sludge.

Shortly after chlorination was abandoned, fall weather and a rainy season commenced. The average sewage flow increased to a peak of 275,000 g.p.d. Within a few days after the change of season the filamentous growths disappeared and a normal, healthy sludge developed, resulting in an excellent effluent. Plant tests made in December yielded the results shown in Table I.

The plant produced a consistently good effluent until the latter part of April, 1936, when hot weather again set in. After about a week of hot weather, the filamentous growths re-appeared and bulking of the sludge commenced.

Characteristic association of the bulking phenomena with periods of hot weather and the failure of all of the previously employed methods of prevention indicated that the cause lay in the effect of high temperatures on the concentrated raw sewage in the sewerage system. Accord-

ingly, on May 8th, 1936, the sewerage system was completely flushed by fire hoses attached to hydrants near the manholes.

TABLE I

Date	Flow		B.O.D. on 24-Hr. Composite		
Dec. 1935	G.P.D.	G.P. Cap.	Raw Sew.	Plant Effl.	% Reduction
19	158,000	35		20	
20	165,000	38	440	35	92
21	172,000	39	277	17	94
22 (Sunday)	158,000	35	206	30	86
23	158,000	35	450	37	92

During the period of flushing the sewage was black and had a strong odor, similar to that of sludge in a digestion tank. The suspended solids content of the 24-hour composite of the raw sewage during flushing, 1610 p.p.m., indicates the amount of sludge which had been deposited in the sewer system, due to flat grades.

pH tests made during the sewer flushing period and throughout the previous summer showed that the raw sewage was consistentlly alkaline.

There was an upset in the plant during the flushing operation due to the extreme sewage strength. However, immediately afterward there was an improvement in results marked by the disappearance of the filamentous growths and the production of an excellent sludge.

An operation procedure was adopted to flush the laterals weekly during periods of hot weather. While each flushing since the first still shows black, partially digested sludge, the concentration of such material is decreasing with each flushing.

Three of the new type aerators, in series, are employed at present; the second and third aerators being operated at lower speeds, and with less power than the first. During flushing periods the primary effluent is discharged into the otherwise idle aerator for pre-aeration, before coming into contact with the activated sludge in the first aerator. This procedure eliminates the upsets caused during the first flushing.

Daily analytical data on the performance of the plant during May, 1936 are shown in Table 2. 5 day B.O.D. and suspended solids tests under "Purification Results" were made on 24-hour composite samples, taken proportional to flow by automatic samplers.

The analyses of daily plant performance for June, July and August, 1936, taken from plant operation records show that a relative stability of 10 + days was continually maintained in the plant effluent, with the exception of three days, July 7th, 8th, and 9th.

The relative stability of the plant effluent during these three days was 6, 5 and 4 days, respectively. Rain, increasing the sewage flow to a maximum rate of 660,000 g.p.d., occurred on July 7th and 8th.

TABLE II.—*Flora, Illinois Sewage Treatment Plant, May,*

TABLE II.—*Flora, Illinois, Sewage Treatment Plant, May—1936*

Note.—All B.O.D. and Sus. Solid Tests from 24 Hour Composite Samples

Date 1936	Temperature Raw Sewage	Flow Data					pH.		Activated Sludge Last Aerator					Purification Results						Power	
				Detention Period										Sus. Solids			5 Day—B.O.D.				
		Flow	Return Sludge	Pri.	Aer.	Final	Raw Sewage	Primary Effl.	pH.	D.O.	S.S. 30 Min.	Sus. Solids	Mohl. Index	Raw Sewage	Plant Effl.	% Red.	Raw Sewage	Plant Effl.	% Red.	Total K.W. Hrs. Daily-Aerators	K.W. Hr./Lb. of B.O.D. Removed
May	°C.	M.G.D.	M.G.D.	Hrs.	Hrs.	Hrs.				P.P.M.	%	P.P.M.		P.P.M.	P.P.M.	%	P.P.M.	P.P.M.	%		
5	15	.202	.092	5.9	11.8	4.1		6.6	7.4	1.4	60	650	920	410	10	97	357	9	97	160	.284
6	15	.184	"	6.5	12.5	4.3		6.8	7.4	4.8	58	580	1,000	340	9	97	365	10	97	160	.295
7	15	.153	"	7.9	14.1	4.9		6.8	7.7	7.4	68	750	905	530	31	94	440	28	94	165	.315
8		.141	"	8.5	14.7	5.2				5.2	56	690	810	1,610	100	94	458	30	93	162	.324
9		.166	"	7.2	13.3	4.5						640		210	48	77	310	3.5	99	160	.376
10		.144	"	8.3	14.5	5.0			7.6	6.8	83	840	990	260	77	70	509	41	92	161	.286
11		.184	"	6.5	12.4	4.3			7.4	1.5	85	590	1,440	310	38	88	390	30	92	160	.293
13	13	.216	"	5.5	11.1	3.8	7.0	7.1				680		330	10	97	356	5	99	158	.250
14		.173	"	6.9	13.0	4.5			7.6	10.7	97	590	1,640	290	2	99	220	2	99	161	.500
15	15	.180	"	6.7	12.6	4.4	7.4	7.3	7.6	11.5	95	500	1,900	305	10	97	324	10	97	160	.340
16	16	.158	"	7.6	14.0	4.9	7.4	7.3	7.6	12.2	72	520	1,380	420	4	99	320	3	99	164	.380
17	17	.130	"	9.2	15.5	5.4	7.4	7.2	7.4	11.6	72	610	1,180	165			216	7	97	163	.740
18	17	.199	"	6.0	12.0	4.2	7.2	7.2	7.6	11.1	75	620	1,210	540	7	99	358	9	97	161	.278
19	15	.153	"	7.8	13.0	4.5	7.3	7.4	7.6	4.8	82	550	1,490	340	4	99	328	12	96	160	.400
20	14	.127	"	9.4	16.0	5.6	7.2	7.2	7.4	8.5	85	600	1,420	225	trace	99	165	3	98	162	.920
21	15	.137	"	8.8	15.0	5.2	7.3	7.2	7.6	3.4	68	560	1,210	190	"	99	285	2	99	161	.491
22	15	.137	"	8.8	15.0	5.2	7.3	7.2	7.6	5.1	50	530	940	320	"	99	420	7	98	161	.340
23	16	.135	"	8.9	15.4	5.3	7.3	7.2	7.6	2.0	50	510	980	450	"	99	358	7	98	164	.410
24	16	.115	"	10.4	16.6	5.6	7.2	7.0	7.4	7.4	39			420	"	99	375	4	99	161	.450
25	17	.166	"	7.2	13.4	4.7	7.2	6.7	7.5	4.5	52	690	750	720	5	99	636	4	99	162	.187*
26		.138	"	8.7	15.0	5.2	7.0	6.6	7.6	2.6	82	760	1,080	280	trace	99	372	5	99	164	.380
27	16	.177	"	6.8	12.8	4.4	7.1	7.1	7.7	2.9	60	670	900	585	"	99	548	6	99	166	.208

* 0.32 K.W.Hr./Lb. B.O.D. Removed based on 368 p.p.m. B.O.D. primary effluent.

The dissolved oxygen content of the plant effluent averaged 3.5 p.p.m. during June, July and August.

5-day B.O.D.'s of 13, 12 and 7 p.p.m. resulted from plant effluent tests made on June 9th, 16th and 24th. Suspended solids in the plant effluent during the foregoing dates are reported as 2, 3 and 4.5 p.p.m. respectively.

These data and operating records indicate the production of a consistently excellent effluent by the plant throughout the hot weather season and the absence of the troublesome bulking condition which had previously occurred in hot weather.

Conclusions

The following conclusions are indicated by the results of operation at the Flora, Illinois sewage treatment plant:

1. The cause of bulking during hot weather was apparently due to the toxic effect of active, partially digested, sewer sludge on the aerobic organisms in the aeration liquor.

2. During hot weather the sludge deposits in the lateral sewers became active. pH tests indicated a stage of alkaline digestion.

3. Successful operation during cold weather apparently was due to accompanying inactivity of the deposited sludge.

4. The solution of the problem of bulking was accomplished by removal of the cause, rather than in the various palliative measures attempted.

5. In general, when plant tests indicate that the operation of the various structures and mechanical equipment should not permit bulking, the condition of the raw sewage should be investigated for the cause.

OPERATION OF THE ALLENTOWN SEWAGE TREATMENT WORKS *

By Harry J. Krum

City Chemist, Allentown, Pa.

The final units of the sewage treatment plant at Allentown, Pa., consisting of 5.12 acres of trickling filters and four humus tanks, were completed and placed in service in May, 1932. Prior to that time, beginning in December, 1929, the treatment consisted only of sedimentation in Imhoff tanks, followed by chlorination. The operating data and a description of the units in operation at that time were presented to this group at the 1931 meeting. (1) A brief description of the plant units and capacities is given by City Engineer Earle W. Meckley in Appendix A.

Sewer System

The City of Allentown has a present population of 98,000. The system for the collection of household, commercial and industrial sewage is separate from the storm water drainage system. The sanitary system consists of the following:

Miles and type of sewer	Size	Cost
7.2 trunk	24 to 60 in.	$ 592,018.75
89.4 district collecting	8 to 24 in.	$1,608,930.75
29.0 collecting to curb line	6 in.	
Total 125.6		

There remain to be constructed in the future, for the completion of the system:

Miles and type of sewer	Estimated cost
11 trunk	$ 762,000
145 district collecting	2,318,000

Although the sanitary sewerage system was designed as a separate system, the increase in sewage flows during rainfall indicates that, undoubtedly, many roof water leads are connected with the system. It is admitted that there is always some infiltration of ground water into the system but infiltration hardly accounts for the increase in flow during rains such as is illustrated in the following table:

Month	Date	Day	Sewage Flow M.G.	River Stage	Weather
July	8	Monday	7.90	4.5	Fair
July	9	Tuesday	11.90	6.0	Rain
July	10	Wednesday	14.10	7.1	Rain
July	11	Thursday	12.15	9.5	Rain
July	12	Friday	9.45	7.7	Fair
July	13	Saturday	8.30	6.7	Fair
July	14	Sunday	7.20	6.2	Fair
Aug.	3	Saturday	7.40	4.3	Rain P.M.
Aug.	4	Sunday	9.18	4.5	Rain A.M.
Aug.	5	Monday	7.98	5.7	Fair

* Presented before the Tenth Annual Conference of the Pennsylvania Sewage Works Association, State College, June 26, 1936.

The necessity for a survey of the existing connections to the system, and the elimination of the illegal connections, is indicated, as well as strict plumbing inspection on all future connections.

TABLE I.—*Sewage Flows by Months*

1935

Million Gallons

Months	Total	Average Daily Flow	Maximum Day	Minimum Day
January	212.57	6.86	7.71	5.43
February	195.27	6.97	7.85	6.26
March	211.98	6.84	7.63	5.71
April	203.57	6.74	7.48	5.60
May	205.21	6.62	7.35	5.45
June	207.04	6.90	7.61	5.67
July	253.00	8.16	14.10	5.80
August	234.75	7.57	8.60	6.02
September	219.35	7.31	9.18	5.95
October	218.77	7.29	8.33	5.95
November	220.58	7.35	8.87	5.95
December	230.62	7.44	8.05	6.40
Total	2612.71			
Yearly Average		7.10		
Maximum			14.10	
Minimum				5.43
1934				
Total	2411.24	Daily Average 6.60		
Maximum			8.59	
Minimum				4.13

The total number of connections to the system at the end of 1935 was 11,236. Estimating five persons per connection, the contributing population is approximately 56,180. Table I shows the daily average flows in December to have been 7.44 million gallons or a per capita flow of 132 gallons per day. The annual average per capita water consumption in the city in 1935 was 160 gallons per day.

TREATMENT PLANT

The sewage flows by gravity to the treatment works located on Kline's Island, within the city limits and seven blocks from the business center of the city. (Fig. 1.) The plant was designed for a population of 128,000 and an average sewage flow of 17.3 million gallons a day; the total cost was $1,500,000. (See Appendix A.) The entire plant is surrounded by a dike as a protection against flood waters. Because of the proximity of the plant to the city, the sewage is comparatively fresh when it is pumped into the detritus tanks. Temperatures of air and sewage are given in Table II.

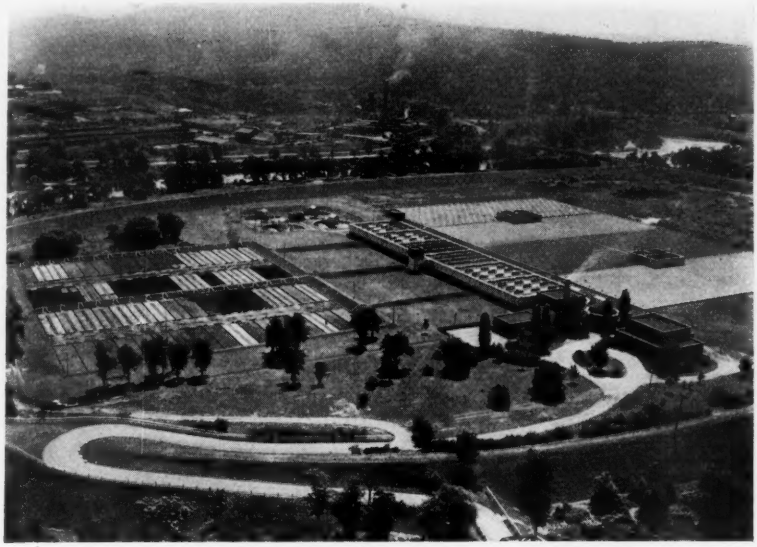


FIG. 1.—Allentown Sewage Treatment Works.

TABLE II.—*Temperature—Degrees Fahrenheit*

Monthly Averages

Month	Air	Sewage	
		Max.	Min.
January	28	61	51
February	29	61	51
March	42	63	53
April	49	64	57
May	53	67	60
June	72	71	63
July	78	71	67
August	72	73	68
September	62	71	66
October	52	70	62
November	46	69	61
December	28	64	55
Average	51		
Maximum		73	
Minimum			51
1934			
Average	52		
Maximum		77	
Minimum			41

Quality of Sewage

The sewage is composed of domestic and industrial wastes. The industries connected to the sewers are silk and rayon dyeing plants, milk pasteurizing plants, breweries and abattoirs. Before permission is granted to an industry to connect with the sewers, a study is made of the waste. Some of the wastes of the dyeing industries are, without harm, passed into the storm water sewers; others, such as abattoir wastes, are passed through holding tanks for the removal of some of the solids and fats before the effluent flows into the sewerage system.

In general the Allentown sewage is a fairly typical American sewage of normal strength. The term " strength of sewage " is difficult to define precisely. McGowan approximated the "strength" of sewage by an empirical formula but Buswell (2) states that "because of differences in analytical methods and character of wastes this formula has not been extensively used in the United States." Lovett and Garner (3) suggest that the strength of sewage may be estimated on the population basis or in terms of oxygen demand in pounds per head of population per day. The daily average of the 5-day B.O.D. in December, 1935, was 200 p.p.m.; the strength of Allentown sewage based on a population equivalent, therefor, is 0.22 lb. oxygen demand per capita per day. This figure is based on daytime samples and is probably somewhat higher than would be the case if 24-hour composites were tested.

Operation

Racks.—As the sewage flows into the pump suction chamber it passes through racks of parallel steel bars having clear spacings of 3 inches. The material collected on these racks is removed manually with a rake and incinerated.

These screenings consist of rags and other coarse materials, some of which pass through the screens and are caught in the impellors of the pumps necessitating occasional opening of the pumps for cleaning. Five hundred cubic feet of rakings were removed from the racks in 1935, representing 1.35 cu. ft. per day or 0.009 cu. ft. per capita per year. It is problematical whether the cost of self-cleaning mechanical screens would have been justified in the original installation for removal of this relatively small amount of material. On the other hand, the hand cleaning of racks is a messy job and is one of the most unpleasant of operating tasks. Furthermore, unless major equipment is provided at the time of construction, it is almost impossible for the operator to secure the necessary funds for its installation at a later date.

Skimming-Detritus Tanks.—Because the present sewage flow is approximately one-half the volume for which the plant is designed, the sewage is pumped into only one of the two detritus tanks. These are 21 ft. deep and 30 ft. in diameter, with inlets and outlets equidistant between the top and bottom. During the 15-minute retention period of the sewage in this tank the coarser solids settle out and the greases

and lighter particles rise to the surface. The floating matter is skimmed off and incinerated. The total amount of skimmings removed in 1935 was 965 cu. ft. equivalent to 2.65 cu. ft. per day or 0.017 cu. ft. per capita per year. (Table III.) The object of the skimming-

TABLE III.—*Skimmings and Screenings—Detritus Tanks*

Cubic Feet

	Skimmings		Screenings				Ash
	Total	Per M.G.	Wet		Pressed		
			Total	Per M.G.	Total	Per M.G.	
January	93.3	.44	484	2.28	279	1.31	35.0
February	76.8	.38	479	2.45	275	1.41	23.3
March	81.1	.38	536	2.53	286	1.35	23.3
April	74.3	.37	517	2.54	293	1.44	26.3
May	72.9	.36	512	2.49	292	1.42	26.3
June	77.9	.36	458	2.18	250	1.21	23.3
July	64.9	.25	422	1.67	235	0.98	23.4
August	70.6	.31	580	2.39	323	1.38	26.3
September	70.0	.36	629	2.87	350	1.60	26.3
October	77.0	.36	712	3.26	402	1.84	29.2
November	98.4	.45	654	2.96	368	1.67	23.4
December	93.7	.36	817	3.54	454	1.96	29.2
Total	964.8		6,780		3,804		315.3
Average	80.4	.37	565	2.66	317	1.46	26.3
Maximum	98.4	.46	817	3.54	454	1.96	35.0
Minimum	64.8	.25	422	1.67	235	.93	23.3
Ave. per day	2.65		18.6		10.4		
1934 Data							
Total	968.0		6,157		3,504		361
Ave. per M.G.		.402		2.55		1.45	
Ave. per day	2.65		16.9		9.6		

detritus tanks is to intercept large quantities of oil, which experience has shown may be dumped intermittently into the sewers, and also to reduce the cost of fine-screen installation by providing screen capacity for only that portion of the sewage flow which carries the coarse and heavier settled solids.

Screenings.—The more readily settleable solids retained in the detritus tanks are concentrated with Dorr plows, the plows being operated for ½ hour periods twice a day. These concentrates are pumped to two Dorr screens where the solids are segregated, pressed in a hydraulic press and the pressed cake burned.

The total amount of wet screenings removed in 1935 was 6780 cu. ft. This volume was reduced with the hydraulic press to 3800 cu. ft., corresponding to 10.4 cu. ft. daily or 0.068 cu. ft. per capita per year. The pressed cake contained approximately 50 per cent of moisture and was incinerated to 325 cu. ft. of ash.

The incinerator is fired with Imhoff tank gas collected by an improvised system which, with the exception to be noted, has supplied more than sufficient gas for the incineration of the screenings and skimmings. During the prolonged cold spell of the 1935–36 winter, however, the Imhoff tanks failed to produce sufficient gas during two months, in which time gas was purchased from the local gas company.

Unfortunately, no temperature readings of the sludge compartment are available but since the Imhoff tanks are 16 feet above ground level on the north side it is obvious that the temperatures in the tanks were reduced below the point where normal biological changes occur.

Imhoff Tanks.—The Imhoff tanks are designed for a 2-hour detention period but at the present rate of flow this period is more than four hours. When sewage was first pumped into the plant, in December, 1929, Imhoff tanks 1 and 2, which are nearest the detritus tanks, were first put in service, later the others from time to time.

The tanks are designed for gas collection, each tank having 15 openings where gas may be collected. While no serious consideration has as yet been given to the installation of a permanent gas-collecting system, the recent advances in the design of sewage-gas internal combustion engines may warrant the utilization of the gas for the pumping of the sewage. Six of the gas vents are equipped with gas domes of our own design and connected with the incinerator.

The Imhoff tanks have caused more operating difficulty than the other units of the plant. It is quite simple to maintain a uniform sludge level in the digestion compartment by reversing the direction of the flow through the tank twice a month but the control of the scum blanket under the sloping roofs of the sludge compartment is one of our greatest problems. Two separate factors are involved: first, the foaming of this scum and second, the increase of the scum layer by the raising of the bottom sludge to the point where it will pass through the slot at the bottom of the settling compartment. When sludge passes through the slot it soon covers the surface of the settling compartment with a mat of sludge. Other than the unsightliness and odor of this scum it does little harm, but is distinctly undesirable from the standpoint of satisfactory operation.

A piping system is available for the removal of scum and sludge from their respective compartments, but no facilities are available for the removal of scum in the settling compartment. Intense and repeated hosing has failed to clear up this unsightly condition, when conditions are such as to foster scum formation. With the present volume of flow it is of course possible to take the offending tank out of service until foaming ceases and then remove the scum with hand screens.

Should the tanks continue to react in a similar manner when the entire city is serviced and the flow equals plant capacity, one remedy would be to install mechanical screens in the Imhoff effluent flumes, thus permitting the removal of the baffles at the effluent ends of the tanks and remove the scum with the screens.

TABLE IV.—*Annual Summary of Sludge Analyses, 1935*

Month	Specific Gravity	Per Cent				pH	Cubic Feet
		Solids	Moisture	Organic	Mineral		
Imhoff 1							
April	1.017	4.77	95.23	69.28	30.72	6.6	23,000
May	1.025	7.82	92.18	62.95	37.05	6.6	23,000
June	1.021	6.20	93.60	64.35	35.65	6.7	13,000
July	1.021	5.10	94.90	62.07	37.93	6.5	27,600
September	1.017	5.12	94.88	65.10	34.90	6.6	23,000
October	1.017	5.28	94.72	66.51	33.49	6.6	22,500
November	1.025	7.16	92.84	69.50	30.50	6.9	6,500
Imhoff 2							
March	1.021	8.62	91.38	50.78	49.22	6.9	
April	1.026	6.49	93.51	62.28	37.72	6.7	23,000
May	1.061	12.63	87.37	39.26	60.74	6.6	11,000
June	1.082	16.74	83.26	36.52	63.48	6.9	24,000
July	1.036	10.55	89.45	47.64	52.36	6.6	6,500
September	1.030	7.07	92.93	50.44	49.56	6.9	11,000
October	1.038	8.58	91.42	49.25	50.75	6.7	2,750
November	1.056	12.40	87.60	37.70	62.30	6.8	2,650
Imhoff 3							
April	1.017	4.40	95.60	50.72	39.26	6.6	38,000
May	1.013	3.56	96.44	65.97	34.03	6.6	45,000
June	1.020	5.10	94.90	64.79	35.31	6.6	29,000
July	1.017	3.93	96.07	60.49	39.51	6.6	31,000
September	1.026	7.21	92.79	50.72	49.28	6.7	28,000
October	1.030	8.26	91.74	46.77	53.28	6.8	27,500
November	1.018	4.21	95.79	60.55	39.45	6.9	22,500
Imhoff 4							
May	1.013	4.22	95.78	70.34	29.66	6.6	
September	1.012	5.42	94.58	68.36	31.84	6.8	500
October	1.029	6.52	93.48	54.37	45.63	6.7	1,100
Imhoff 5							
June	1.017	4.63	95.37	61.31	38.69	6.6	33,000
July	1.022	5.17	94.83	56.72	43.28	6.6	11,000
September	1.014	5.60	94.40	57.23	42.77	6.8	11,000
October	1.025	6.53	93.47	56.75	43.25	6.9	17,000
November	1.021	5.35	94.65	58.54	41.46	6.8	18,000
Imhoff 6							
April	1.018	5.51	94.49	59.27	40.73	6.8	18,000
June	1.023	5.92	94.08	61.10	38.90	6.9	23,000
July	1.025	5.63	94.37	54.49	42.51	6.9	24,000
September	1.019	5.77	94.23	54.92	45.08	7.0	27,500
October	1.031	7.26	92.74	52.02	47.98	6.9	27,500
November	1.022	5.50	94.50	57.09	42.91	6.9	17,000

Table IV shows the volume and analytical data of the sludge in storage during 1935 in the various tanks. Composites are made of the samples on the same plane, that is, 3, 6, 9, etc. foot levels, starting at the bottom. The average pH of the sludge was 6.8, the minimum being 6.5 and the maximum 7.0.

Tanks 1, 2, 3 and 4 have periodically performed abnormally, and while Tank 5 has functioned more satisfactorily than the above mentioned, at times, hosing was necessary to control foaming. Tank 6 has operated most satisfactorily of all and has been taken out of service only once because of foaming.

An analysis of a sample of foaming sludge collected as it was flowing from the gas collecting vent into the settling chamber shows the following results:

Total Solids	Volatile Matter	Petroleum Ether Ext.
4%	96%	31%

One of the reasons for the abnormal operation of the tanks nearest the detritus tanks may be the difference in volume of sludge collected in the several tanks. This is illustrated in the following table:

Operating Data of the Imhoff Tanks—1935

Tank	Month in service	Volume sludge removed cu. ft.
1	12	46,000
2	12	39,000
3	12	32,000
4	5	43,000 X
5	8	12,000
6	11	23,000

X = Sewage sludge and all sludge from humus tanks.

Scum and sludge depths are measured monthly and samples are taken at the same time for analysis.

Trickling Filters.—Supplementing the sedimentation of the sewage in the Imhoff tanks is the oxidation in the trickling filters, the area provided for this purpose being 5.12 acres divided into four units. Fixed nozzles (Fig. 2) distribute the settled sewage, intermittently, onto the crushed limestone (10 ft. deep) whence it flows to the underdrain system, which consists of concrete brick on ends over concrete channels. There are two dosing units (Fig. 3) each divided into two pairs of chambers equipped with alternating siphons. Half of the trickling filter area has been in operation for four years and the remaining area will be used when the sewage flow warrants. The filters were dosed with an average of 2.66 m.g. of sewage per acre per day in 1935.

The routine method of operation is to flush the laterals, the flushed liquor being mixed with the raw sewage in the pump suction chamber. Very little additional attention is required by the filters.

The time and labor involved in the cleaning of nozzles in the first two months of filter operation was greater than anticipated. It was obvious that if the particles carried over from the Imhoff tanks were

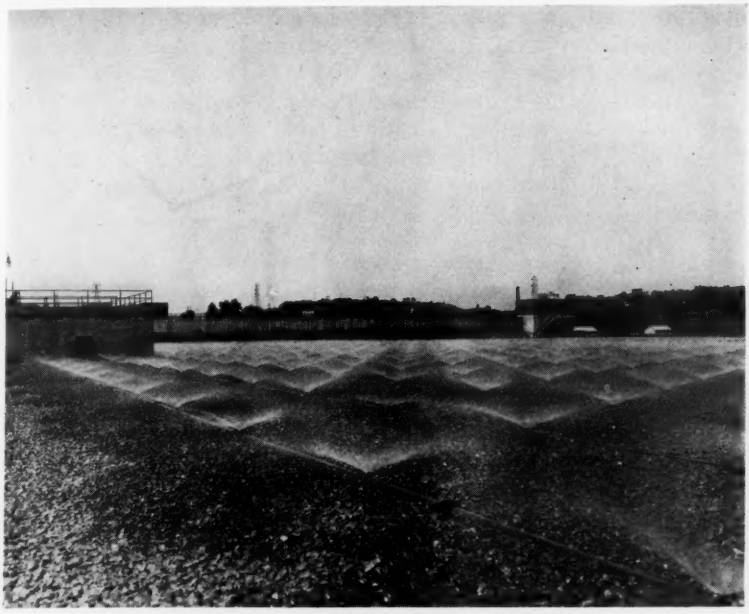


FIG. 2.—Allentown trickling filter in operation.

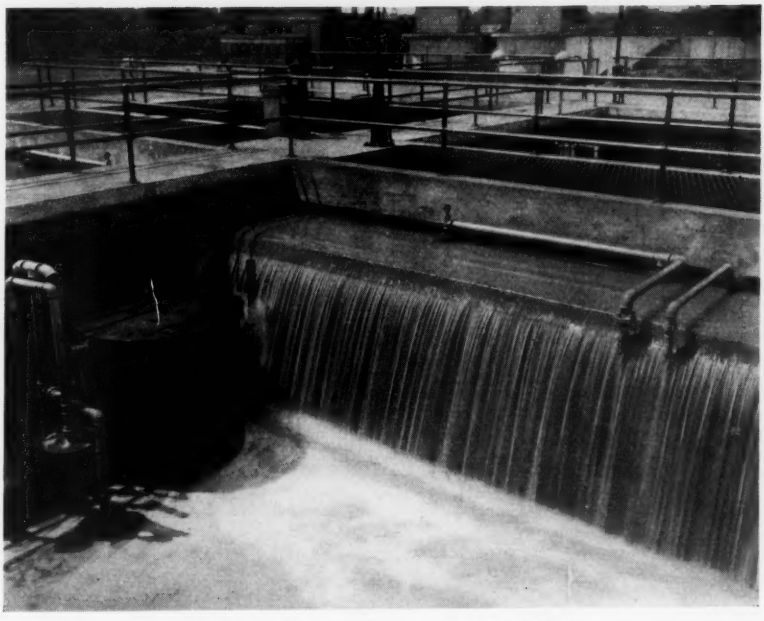


FIG. 3.—Dosing chamber for trickling filters.

removed no extra labor would have to be employed. In the completed structure provision was made for mechanical screens in the Imhoff effluent channel, but because of lack of funds the screens were not installed. In the latter part of August, 1932, removable screens, built and installed by the employees at the plant, were placed at convenient points for the purpose of determining what effect they would have on the number of nozzle cleanings. The following tabulation shows the beneficial result of that experiment:

	Number of Nozzles Cleaned
June	2532
July	2590
August	1084
September	206
October	501

The result was so satisfactory that the screens have been kept in use and are cleaned regularly as a part of the operating routine.

The two filters in use contain 578 nozzles, of which an average of 30 a day were cleaned in 1935. The time required for flushing the laterals and cleaning of nozzles was 1 man-hour per day.

No provision is made for the flooding of the filters for *psychoda* control, the thought being that if the flies become a nuisance, other remedial measures might be applied.

Several years ago an attempt was made to control an undue prevalence of flies by superchlorinating the sewage flowing to the filters. No definite conclusions were reached because the flies have not been sufficiently numerous since then to warrant the expenditure of time and money for fly control, although the results obtained appeared fairly promising.

Chlorination.—The trickling filter effluent is chlorinated as it flows to the secondary settling tanks. This is necessary because the City of Bethlehem, located 4 miles down stream, takes its water supply from the Lehigh River.

Twenty tons of chlorine were applied to the sewage in 1935, corresponding to a dosage of 14.82 pounds per million gallons or 1.78 parts per million (Table V). This treatment resulted in an average residual chlorine in the effluent of the final settling tanks of 0.35 parts per million.

The chlorine is purchased in ton cylinders and stored in the open on concrete supports adjacent to the chlorinating house. The chlorine tanks operate satisfactorily even though they are subject to the seasonal variations in the temperature of the air. It is important, however, to maintain a fairly constant temperature, particularly in the winter, in the room housing the three manually operated vacuum type chlorinators. A coal stove was found more economical and more satisfactory than the electric heater originally installed in this room. Last Fall, gas from a few of the gas vents on nearby Imhoff tanks replaced coal as the source of fuel in the stove.

TABLE V.—*Chlorine Applied to Sewage, 1935*

Period	Total Chlorine Pounds	Quantity of Sewage Treated M.G.	Dosage	
			Pounds per M.G.	Parts per Million
December 20 to January 8	2,000	105.77	18.91	2.25
January 9 to January 24	2,000	129.56	15.44	1.85
January 25 to February 15	2,000	154.35	12.96	1.55
February 16 to Mar. 8	2,000	145.00	13.79	1.74
March 9 to March 29	2,000	145.15	13.79	1.65
March 30 to April 25	2,000	182.32	10.97	1.32
April 26 to May 15	2,000	132.95	15.04	1.81
May 16 to May 27	2,000	85.63	23.36	2.80
May 29 to June 13	2,000	108.97	18.35	2.20
June 14 to July 1	2,000	125.53	15.93	1.91
July 2 to July 19	2,000	152.55	13.11	1.57
July 20 to August 5	2,000	132.69	15.07	1.81
August 6 to August 22	2,000	129.41	15.45	1.85
August 23 to September 13	2,000	163.15	12.26	1.47
September 14 to October 1	2,000	129.10	15.49	1.86
October 2 to October 21	2,000	139.80	14.31	1.72
October 22 to November 8	2,000	128.40	15.58	1.87
November 9 to December 2	2,000	178.65	11.20	1.34
December 3 to December 20	2,000	135.10	14.80	1.77
December 21 to January 13	2,000	187.75	10.65	1.27
Total	40,000	2,791.82		
Average			14.82	1.78

The one-inch water line connected with the chlorinators was found to be too small to operate the three chlorinators simultaneously. This was replaced with a two-inch line and resulted in satisfactory operation of the three units.

Humus Tanks.—The chlorinated trickling filter effluent flows to two of the four humus (secondary settling) tanks designed for a settling period of 1¾ hours. This actual time period for part of the flow is much shorter as determined by the fluorescin dye test, indicating short circuiting. At the end of a month of service the other two tanks are substituted for the first two in order to keep the mechanical units in good operating condition.

When these units were put in service the Hardinge plows were operated 2 hours and the pumps 30 minutes each day, the sludge being pumped into the Imhoff tanks.

This addition of humus sludge to the Imhoff sludge compartments caused unsatisfactory conditions, so Tank 4 was set aside for the separate digestion of this sludge. This digested sludge drained and dried as rapidly as Imhoff sludge.

In the Fall of 1935, after making minor changes in the piping system, the humus sludge was applied directly to the beds. The compara-

tively few beds available for this purpose necessitated the daily application of sludge in layers until a bed was filled. This sludge contained 88 per cent of moisture after being on the beds for 8 months, showing the impracticability of this method. Investigations are being made for the purpose of increasing the drainability of humus sludge by the addition of alum or ferric chloride; laboratory tests indicate the latter to be more effective. Alum has been used on a few test runs under normal operating conditions; but the few tests made do not justify conclusions at this time.

The present practice is to operate the plows and pumps every third day, thereby accumulating sufficient sludge to fill one drying bed. In 1935 the amount of humus sludge was approximately 0.005 cu. ft. per capita per day and it contained 3 per cent solids and 97 per cent moisture.

Drying Beds.—The 3.38 acres of open drying beds are divided into 68 units, each being provided with narrow gauge railway tracks on which a train of 6 one cubic yard dump cars operate; the cars being moved about with a 4-cylinder gas engine. As is customary with Imhoff installations no sludge is drawn from the Imhoff tanks in the winter months.

TABLE VI

Sludge Applied to Drying Beds			Sludge Removed from Beds	
Date	Imhoff Tank No.	Cubic Feet	Month	Cubic Feet
May 8	2	15,840	April	405
May 17–18	1	14,400	May	22,005
May 23–24	3	20,160	June	7,398
June 10	4	14,400	July	5,832
June 14	5	11,520	Aug.	1,836
June 18	6	10,080	Sept.	6,129
June 20–21	4	8,640	Oct.	8,586
July 3	1	10,080		
July 10	2	17,500		52,191
July 20	4	20,160		
July 30	1	10,080		
October 7	2	5,500		
October 10	1	11,520		
October 16	3	11,520		
October 19	6	11,520		
		192,920		

Table VI shows that 192,920 cu. ft. of sludge were applied to the drying beds in 1935, corresponding to 0.0096 cu. ft. per capita per day. The dried sludge removed amounted to 52,191 cu. ft. or 0.0025 cu. ft. per capita per day. The sludge removed from the beds contained approximately 51 per cent moisture.

The sludge is removed from the beds by two employees. The dried sludge is used by the Park Department and individuals as a fertilizer on farms and lawns with such success that the demand has always exceeded the supply. No charge is made for this sludge.

Analytical Data

Sampling for Analyses.—Daily composite samples are made of the hourly samples of raw sewage, Imhoff effluent, filter effluent and humus tank effluent. These samples are tested for settleable solids and pH. The daily composite samples are preserved and combined into weekly composite samples and subjected to complete analyses. Daily catch samples are also taken for the determination of 5-day biochemical oxygen demand and bacteria tests.

It is unfortunate but unavoidable that the trickling filter samples must be taken at the inlet of the humus tank; unfortunate because when this sample is taken it has been in contact with chlorine for two and one half minutes; unavoidable, because of the impossibility of obtaining a representative sample at any other point. The points that are available are, because of structural characteristics, invariably covered with a layer of scum and the several devices that have been constructed for collecting representative samples were found unsatisfactory. To offset as much as possible the effect of chlorine, the B.O.D. sample is dechlorinated immediately with thiosulphate and seeded with raw sewage when analyzed.

Yearly Summary, 1935

The averages of the analytical results for 1935 are shown in Table VII. The annual percentage reductions of the various constituents are also shown. These results indicate that the complete treatment reduced the total nitrogen 78.5 per cent, suspended oxygen consumed 87.1, total suspended solids 81.2, oxygen demand 86 and bacteria more than 99 per cent. The nitrogen as nitrates in the final effluent was 5.2 p.p.m. The daily methylene blue tests of the final effluent in 1935 showed relative stabilities invariably 84 per cent or greater. The samples tested for stability are ordinarily kept only five days, consequently it is not known how much longer these samples would keep without decolorization nor how much higher the stabilities might have averaged.

River Analysis

Weekly tests are made of the Lehigh River, into which the final effluent of the treatment plant flows. Samples were taken above and below the treatment plant, and the results of analyses are summarized as monthly averages in Table VIII. The saturation of dissolved oxygen in the river above the city was 94 per cent and at Bethlehem

TABLE VII.—*Chemical Analyses—Yearly Averages*

Parts per Million

Constituents	Raw	Imhoff Tank Eff.	Trickling Filters Eff.	Humus Tank Eff.	Per Cent Reduction
Organic Nitrogen					
Total	17.05	11.20	6.06	3.66	78.55
Dissolved	5.72	5.47	3.34	2.13	62.76
Suspended	11.33	5.79	2.72	1.53	86.51
Ammonia Nitrogen	12.23	13.50	1.23	1.05	91.41
Nitrite Nitrogen	.09	.09	.47	.27	
Nitrate Nitrogen	.60	.60	5.12	5.23	
Oxygen Consumed (100° C. 30 min.)					
Total	129	67	42	31	75.96
Dissolved	36	32	23	19	47.22
Suspended	93	35	19	12	87.09
Residue on Evaporation					
Total	688	570	543	519	24.56
Loss on Ignition	430	344	311	288	33.02
Fixed Residue	258	226	232	231	10.46
Dissolved Solids					
Total	502	482	489	484	3.58
Loss on Ignition	277	270	268	261	5.77
Fixed Residue	225	212	221	223	0.88
Suspended Solids					
Total	186	88	54	35	81.18
Loss on Ignition	153	74	43	27	82.35
Fixed Residue	33	14	11	8	75.75
Chlorides as Cl	96	92	93	92	
Alkalinity as $CaCo_3$	198	216	133	123	
Iron as Fe	1.03	.65	.6	.4	
Oxygen Demand					
5 day B.O.D.	213	84	35	29	86.00

Bacteriological Analyses—Yearly Averages

	Raw	Humus Tank Effluent	Per Cent Reduction
Bacteria per cc.			
Agar—37°	1,800,000	1500	99.92
B. coli	190,000	10	99.99+

TABLE VIII

Lehigh River Data

Annual Summary, 1935

Monthly Averages

	Jan.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ave.
River Stage	8.2	8.1	7.8	7.5	7.8	7.8	7.8	7.6	8.4	8.6	8.0
River Flow (C. F. S.)	2,230	1,967	1,400	1,033	1,400	1,400	1,400	1,100	2,630	2,900	1,746

No samples collected in February and March.

ABOVE ALLENTOWN—TILGHMAN ST. BRIDGE

Color	13	12	11	7	8	5	8	6	15	10	10
Turbidity	19	12	3	3	3	3	2	3	15	5	7
Stability—days	20	20	20	20	20	20	20	20	20	20	20
Stability—per cent	99	99	99	99	99	99	99	99	99	99	99
Dissolved O_2											
Temp. Deg. C.	6	12	18	23	23	25	19	16	11	6	16
P.P.M.	12.0	10.6	9.0	7.5	7.7	7.6	8.5	9.2	10.2	11.8	9.4
Per cent saturation	96	94	93	88	88	91	91	92	92	94	94

Bacterial Examination—Counts per Cc.

Agar—37° C.	55	8	17	160	80	110	35	3	425	50	96
Gas-Index	0	0	2.6	4	5	0.3	0.5	0	7	5	2.4
EMB Count	0.3	0.7	0.8	7	2	1.3	1.0	0	12	8	3.0

BELOW ALLENTOWN—BETHLEHEM WATER WORKS INTAKE

Color	10	12	11	7	5	8	10	6	15	7	9
Turbidity	10	8	3	2	3	8	7	6	16	4	6.7
Stability—days	20	20	20	20	20	20	20	20	20	20	20
Stability—per cent	99	99	99	99	99	99	99	99	99	99	99
Dissolved O_2											
Temp. Deg. C.	5	11	17	22	23	25	18	14	11	6	15
P.P.M.	12	10.1	8.4	6.3	7.3	7.3	7.5	7.6	9.4	10.9	7.5
Per cent saturation	90	89	85	71	84	87	80	74	85	87	71.4

Bacterial Examination—Count per Cc.

Agar—37° C.	170	80	380	1,500	2,500	4,000	1,600	2,500	800	120	1,300
Gas-Index	3.7	7	8	37	5	10	50	37	10	5	17
EMB Count	21	14	6	32	25	31	46	28	18	9	23

Water Works intake 71.4 per cent. In this connection it should be noted that considerable sewage and industrial wastes, as well as storm drainage, continues to reach the river and its tributaries without treatment.

COST OF OPERATION

The cost of operation of the sewage treatment plant in 1935 is shown in the following table:

Item	Cost
Labor:	
1 Chief Operator 3 Operators 4 Ass't. Operators 1 Ass't. Chemist	$13,330.00
Miscellaneous Labor (3 men—part time)	3,293.25
Power	8,801.96
Supplies (chlorine, gas, coal, etc.)	2,970.52
Cost per m.g.	$ 10.87

These costs do not include fixed charges. The cost per million gallons will of necessity decrease with the increase in sewage flows.

Grounds.—The trees, bushes and hedges have grown remarkably well in the past 6 years; these with the well kept lawns and driveways present a scene of beauty rarely found at treatment plants.

Summary

The preliminary treatment features of the plant have operated well and incineration of rakings, scum and screenings with Imhoff tank gas has been successful. The Imhoff tanks, even though efficient, have shown the not uncommon tendency to work upside down but the trickling filters have demonstrated their reliability and freedom from trouble. Even the *psychoda* fly has not been troublesome except on one occasion of short duration.

Sludge drying has been accomplished with ease and the dried sludge has been disposed of for fertilizer without difficulty.

Chlorination and final sedimentation have produced an effluent which, when discharged into the Lehigh River, has been adequately assimilated by the stream. Operating costs have been remarkably low.

Acknowledgment

Acknowledgment should be made of the helpful cooperation of City Engineer Earle Meckley and of the conscientious, faithful and able supervision of Chief Operator Warren Heimbach. The analytical work has been carried out efficiently and accurately by my assistants, Mrs. Hersh, Mrs. Clewell and Paul Miller.

I would be ungrateful indeed if I failed to acknowledge the invaluable advice, in the operation of the plant as well as the helpful suggestions in the preparation of this paper, of E. Sherman Chase of Metcalf and Eddy, the designers of the plant.

References

1. Harry J. Krum, "Allentown Sewage Treatment Works," THIS JOURNAL, 3, page 647 (1931).
2. Arthur M. Buswell, "The Chemistry of Water and Sewage Treatment," page 211 (1928).
3. M. Lovett and J. H. Garner, "Strength of Sewage," THIS JOURNAL, 8, 338 (1936).

Appendix A

SEWAGE TREATMENT WORKS, ALLENTOWN, PA.

Description of Plant

By Earle W. Meckley

City Engineer

The City of Allentown has a population of 98,000, which is served by a separate sewerage system. The treated sewage flows into the Lehigh River, which flows through the city. Five miles down stream is located the City of Bethlehem whose water supply is taken from the river. Eighteen miles east of Allentown, the river joins the Delaware River.

The sewage of the city flows by gravity to the sewage treatment works constructed on Kline's Island located in the Lehigh River down stream and south of Hamilton Street. The island is within the city limits but is more or less isolated because the railroads occupy both banks of the river opposite the plant, making the area industrial rather than residential. The entire island is surrounded by a dike to elevation 32.0 City Datum, six feet higher than the maximum recorded flood level.

The treatment plant was completed and placed in service in May, 1932, and was designed and construction supervised by City Engineer, Earle W. Meckley and Consulting Engineers Metcalf and Eddy, of Boston, Mass.

The plant consists of a rack chamber, pumping station and laboratory, two detritus tanks, screen and incinerator house, six Imhoff tanks, ejector house, chlorinating house, sludge beds, trickling filters, four humus tanks and garage. It was designed for an estimated population of 128,000 in 1935 with an average daily flow at that time of 17.3 m.g. and a maximum of 34.6 m.g. The capacity of the main sewer entering the plant is 59 m.g.d. The plant is so arranged that similar duplicate units may be added to double the present capacity. The incoming sewer is provided with an overflow for emergency use only, such as might result from interruptions of power.

Rack Chamber.—A rack chamber is provided to prevent large objects from entering the pumps. The racks are made of parallel steel bars in three sections, each 9½ ft. long by 1 ft. 10 in. wide, having a clear spacing of 3 inches.

Pumps.—The main pumping equipment consists of three motor-driven centrifugal pumps. These pumps comprise a 4,000 g.p.m. (5.76 m.g.d.) pump direct connected to a 60 hp. motor; and 8,000 g.p.m. (11.52 m.g.d.) pump connected to a 125 hp. motor; and a 12,000 g.p.m. (17.3 m.g.d.) pump connected to a 140 hp. motor. Provision is also made for the installation of a fourth pump and motor when necessity warrants it. Between the two larger pumps is located a 300 hp.

Sterling gas engine which may be connected with either of these pumps by a chain drive and clutch, thereby guarding against interruption of service in the event of loss of electric power.

Vacuum System.—The pumps are primed with duplicate units of the Nash Hytor rotary vacuum pumps with a vacuum pump and a suction riser. The pumps are automatically primed when the vacuum drops to 15 inches. A Builders Iron Foundry venturi meter is located on the pump floor with bypass provided around this meter.

Switchboards.—The switchboards, located in the pump house, are of the removable truck type and comprise eight trucks manufactured by the Condit Electric Manufacturing Company. Two of the trucks are on the incoming power lines; one is the instrument truck; one is a 440-volt truck to operate the motors in the screen house, the ejectors and the detritus tank plows; and four trucks control the pumps, one for each of the pumps with a spare for an additional pumping unit.

Detritus Tanks.—Two detritus tanks, each 30 ft. in diameter and 21 ft. deep, are provided with two wooden booms for skimming purposes and with Dorr mechanism for collecting settled solids. The tanks are designed for a 15-minute sedimentation period.

Screen House.—In the screen house are two 2,000 g.p.m. motor driven centrifugal pumps. These pumps raise the settled solids in the detritus tanks to two fine screens (Dorr) in the screen room. These screens are 5 ft. in diameter and have ⅛ in. slots. The screenings are picked up by bucket elevators and deposited in hoppers, from which they are taken for pressing. The press is manufactured by the Hydraulic Press Manufacturing Company. The solids are burned in the incinerator, which is also located in the screen house.

Imhoff Tanks.—There are six Imhoff tanks, each 75 by 65 ft. in plan and 32 ft. deep. They are designed for six months' sludge storage capacity at 3.4 cu. ft. per capita, and with an average sedimentation period of two hours. Provision is made for reversal of flow. Our practice is to reverse the flow every 15 days. The tanks are so built that gas collecting apparatus may be installed when desired. Sludge is removed from the tanks by gravity to the sludge drying beds or to the ejectors. Spray pipes encircle the sludge compartment for flushing the sides. Six sludge inspection chambers are built in each tank to permit the operator to observe the character of the sludge as it is being drawn from the sludge compartment. Piping is also provided for the removal of scum.

Ejector House.—In the ejector house are located two ejectors with a capacity of 50 cu. ft. each. They automatically alternate in filling and discharging, the time required being one-half minute for each operation. A dry-feed lime machine connects with the ejectors for the adjustment of the pH of the sludge.

Chlorinating House.—The chlorinating house contains three Wallace and Tiernan vacuum type chlorinators. Chlorine is purchased in one-ton cylinders and is stored on cradles outside the building, from which point it is piped to the chlorinators.

Sludge Beds.—There are 3.38 acres of sludge beds designed for seven applications per year during ten months of the year. The beds are divided into 68 compartments, each 18 by 80 ft. Each bed has 13 in. of graded gravel and 9 in. of graded sand.

Trickling Filters.—There are 5.12 acres of trickling filters filled with crushed limestone 10 ft. deep. The stone varies in size from 1 to 2½ ins. The trickling filters are divided into four units, which are connected to four sets of twin dosing tanks. Dosing period 2 min. 20 sec.; rest period 40 sec., for maximum flow. Head on nozzles 6.5 ft. max. and 1.5 ft. net terminal head. Nozzles are Worcester Type B dome ⅞ in. orifice. Nozzle spacing 13 ft. The floor system is the concrete precast grid type.

Humus Tanks.—There are four circular humus or secondary sedimentation tanks arranged about a humus pumping station. Thickening apparatus made by the Hardinge Co. of York, Pa., is installed in each tank. The tanks are 70 ft. in diameter with cone shaped bottoms, 10 ft. 6 in. to 15 ft. 6 in. in depth. Sedimentation period is 1½ hrs.

Cost.—The total construction cost of the entire plant was $1,500,000.

Discussion of Paper by Harry J. Krum,

Operation of the Allentown Sewage Treatment Plant

By E. Sherman Chase *

It is now about ten years since the studies were made which led to the design and construction of the present sewage treatment plant at Allentown. During those ten years much research has been carried out upon the fundamental processes underlying the art of sewage disposal and a voluminous literature upon the subject has been produced. It is interesting therefore to give some consideration to the reasons which governed the selection of the type of treatment adopted for Allentown and to look into the historical background of the sewage problem of the city. It is also interesting to inquire as to what if any modifications in type of treatment or in plant design are indicated by the research of the past ten years and by the actual operating experiences with the Kline's Island plant.

In 1925, at the time of our investigation of the sewage disposal problem of Allentown, about 10 per cent only of the population were connected with a sewer system. The design of a comprehensive system of sewers was under way and by December, 1935, construction had progressed to such an extent as to result in about 57 per cent of the population being connected to the sewers.

The flow from the population connected to sewers in 1925, amounting to about 1 m.g.d., was then treated in a so-called "Direct Oxidation" plant on the banks of the Little Lehigh River into which the effluent was discharged. This treatment plant was built in 1921 and

* Metcalf and Eddy, Boston, Mass.

the treatment consisted of the application of lime to produce caustic alkalinity, passage through banks of electrodes discharging direct current through the lime treated sewage, and sedimentation of the effluent from the electrolizer units.

A very careful test run of this plant was carried out for one week in October, 1925. A comparison of the results obtained on this test of the direct oxidation process and those obtained for the present treatment plant in 1935 are shown in Table I.

TABLE I.—*Comparison of Operation of Direct-Oxidation Plant and Imhoff-Trickling Filter Plant, Allentown, Pa.*

Analyses of Effluents

	Parts per Million		Per Cent Removed	
	Direct-Oxidation Plant Oct. 1925	Imhoff-Trick. Filter Plant 1935	Direct-Oxidation	Imhoff-Trick. Filter
Organic nitrogen	6.08	3.66	19.1	78.6
Ammonia nitrogen	10.37	1.05	32.6	91.4
Oxygen consumed	94	31	39.3	76.0
Suspended solids	50	35	64.0	81.2
5-day B.O.D.	122	29	35.1	86.0
Nitrite nitrogen	0.54	0.27	—	—
Nitrate nitrogen	1.12	5.23	—	—
Relative stability—per cent	30	84+	—	—
Bacterial count				
Agar—24 hr.—37° C.	2330	1500	99.7	99.9+
B. Coli	724	10	99.4	99.9+

Operating Data

	Per M.G. Treated	
Lime	1 ton	—
Electricity	232 kwh.	—
Sludge (wet)	5,350 gal.	610* gal.
Sludge (dry solids)	4,550 lb.	265* lb.
Operating costs	$47.00†	$10.87‡
Fixed charges (capacity)	$16.85	—
Plant cost per m.g.d.	$69,500	$86,800*

* Approximate.

† 1925, approximately 1 m.g.d.; estimated for 3 m.g.d. = $33.10.

‡ 1935, includes low lift pumping.

It should be noted that the rated capacity of the direct oxidation plant was 3 m.g.d. but that only one of three electrolizers were operated. Consequently the electrolytic part of the process was operated at capacity, but the sedimentation tank was operated at about one-third capacity. In the case of the present treatment plant, the trickling filters and humus tanks in service have been operated at about their

rated capacity, whereas the Imhoff tanks and sludge beds have been operated at about one-half capacity. It is reasonable to expect that with the electrolytic plant operating at capacity its final effluent would have been somewhat worse than at the time of the test run, but that the final effluent of the present treatment plant (when the full load is carried) will remain substantially the same as it was in 1935.

From the table it will be seen that the purification effected by the electrolytic process was far less than that by the present plant and the cost per million gallons far more. Furthermore, the sludge disposal problem at the electrolytic plant had not been solved at the time the plant was abandoned.

Whenever a new sewage plant is proposed, it is necessary to predict, insofar as possible, certain basic data with respect to future sewage flows and sewage composition. It is of interest, therefore, to compare what actually happens with predictions. Such a comparison is shown in Table II.

TABLE II.—*Comparison of Predicted and Actual Data*

	Prediction	*Actual*
1935 Population	127,750*	98,000*
1935 Sewage flow (m.g.d.)		
Total	17.3*	7.44 (Dec.)†
Per capita, gal. daily	135	132†
Cost—Construction		
Total	$1,902,600	$1,500,000
Per m.g.	110,000	86,800
Cost—Operation		
Annual	$80,000	$28,395.73
Per m.g.	12.50	10.87
Composition of sewage—p.p.m.		
Organic nitrogen—p.p.m.	10.7	17.05
5-day B.O.D.—p.p.m.	195	213
Suspended solids—p.p.m.	178	186
24 hr. 37° C. Agar count per cc.	1,000,000	1,800,000
B. Coli per cc.	200,000	190,000

* Entire city.
† Connected population.

This table shows that the population has not grown as anticipated and that the flow of sewage tributary to the treatment plant has reached somewhat less than one-half the designed capacity of the plant. On the other hand the per capita flow of sewage is almost exactly that predicted. The construction cost was materially less than estimated, due, in part, to the fact that the construction of the trickling filter and accessories was delayed about a year, at a time of falling prices. Operating costs per million gallons treated were less in 1935 at half-load than were predicted for full load. This fact shows the efficient and economical management of the plant. The strength of the raw sewage has been about as predicted, being somewhat higher in organic nitrogen than was anticipated. On the whole, the predictions were reasonably

accurate, except in the matter of population growth and costs. Failure to hit these items more closely may be laid at the door of the depression. It is probably safe to say that the depression has saved the city nearly half a million dollars in sewage treatment costs, construction, and operation.

In determining the type of treatment to be adopted, it was immediately recognized that, due to the fact that the water supply of Bethlehem is taken from the Lehigh River, just below Allentown, a high degree of purification was required. There were four projects studied in detail, namely Imhoff tanks—trickling filters; activated sludge with dewatering of excess sludge; Imhoff tanks—activated sludge; and sedimentation-activated sludge—separate sludge digestion. The "Direct Oxidation" process was eliminated due to its high cost of operation and the relatively low purification effected. Choice of the Imhoff-tank-trickling filter plant was based upon two major reasons; first, lowest total annual costs, and second, simplicity and reliability. Looking backwards, in the light of experience, I see no reason to regret the choice of treatment.

The plant has been relatively free from operating difficulties and those experienced have not been unusual nor have they materially affected the cost of operation nor the quality of the effluent. Sewage treatment, at its best, offers more or less difficulty and most new plants necessitate a period of adjustment and the ironing out of kinks in the performance of equipment. Plants involving sludge digestion require greater or less time in which proper digestion may become established. The establishment of proper digestion at Allentown was a little difficult and before satisfactory conditions were fully obtained certain of the tanks gave foaming trouble. Furthermore, there has been a tendency for some of the tanks to "work upside down." The disposal of humus tank sludge by pumping back to the digestion compartments of the Imhoff tanks has not worked out satisfactorily, although this procedure has been followed with success at Fitchburg, Mass., for many years. As regards the trickling filters, it may be said that they have operated very successfully, with no pooling nor ponding and with relatively few filter flies. The filter material was selected and placed with great care.

In connection with the operation of Imhoff tanks there appear to be certain precautions to follow. In starting a tank for the first time it is desirable that it be started in the late spring or early summer in order that favorable digestion temperatures be available. If possible the tank should be seeded with sludge from some other digestion tank in which digestion has become established. Furthermore, the tank should be started up well under design load and brought to full load gradually. When proper digestion is once established it is very important to avoid withdrawing too large a proportion of digested sludge. In general, the more sludge that can be allowed to remain in the digestion compartment, the better. If a tank does foam and work upside

down, the foaming scum should be drawn to the sludge beds, hosed or, in some cases, treated with lime. Lime treatment of sludge and scum in Imhoff tanks is often a difficult matter and is not always sure of success. With time, proper seeding and favorable temperatures, proper digestion of sludge may be expected. The difficulty comes from not having these three factors available.

In closing, I wish to say a word of praise for Mr. Krum and for Mr. Heimbach, for the intelligent and conscientious care with which the Kline's Island plant has been operated. The appearance of the plant and the character of the effluent attest this care.

SLUDGE FILTRATION AT SPRINGFIELD, OHIO *

By A. B. Cameron

Formerly Operator, Sewage Treatment Works, Springfield

This paper is primarily a progress report on mechanical sludge filtration at Springfield. For reasons which will be given in detail many of the theories are tentative in nature and are subject to change, modification or rejection when we have more definite and complete data.

The Springfield plant was placed in operation May 1, 1935, and has operated continuously since that date. During the early months of operation the flows received at the plant were extremely low as only part of the sewerage system was connected to the plant. Final connection of the interceptors was completed July 6, 1936.

Plant.—The plant is of the separate sludge digestion type, employing only primary treatment followed by chlorination during the dry summer months. It comprises a main building which houses the bar screen, incinerator, chlorinating equipment, vacuum filter, offices and laboratory, and several small buildings housing the auxiliary units, Dorr detritor, Dorr Sifeed clarifiers and Dorr digesters.

Quantity of Sewage.—Normally about eleven million gallons of sewage reach the plant per day. At times of heavy rain fall the flows are greatly increased and about thirty million gallons are admitted to the plant. The balance is bypassed immediately ahead of the screen chamber. At present it is planned to divert about two million gallons of clear water that now reach the sewers, thus we will eventually be treating about nine million gallons per day.

Quality of Sewage.—To date the sewage would be termed rather weak and fresh with little industrial wastes present, as shown by the following data:

Table I

(Approximate analysis)	
Settleable solids cc. per liter, 2 hours	3.5
Suspended solids, parts per million	160
B.O.D. 5 day 20° C., parts per million	146
Dissolved oxygen, parts per million	0.5

Operating Results.—To date the results of operation have proven to be very satisfactory, as shown by the following data:

Table II

Percentage removal of suspended solids	59.4
Percentage reduction of organic matter in digesters	60.2
Cu. ft. gas collected per capita per day	0.94
Parts per million of chlorine required to give 0.2 p.p.m. residual in plant effluent	5.0

(Flow sheet of the plant is appended to this paper.)

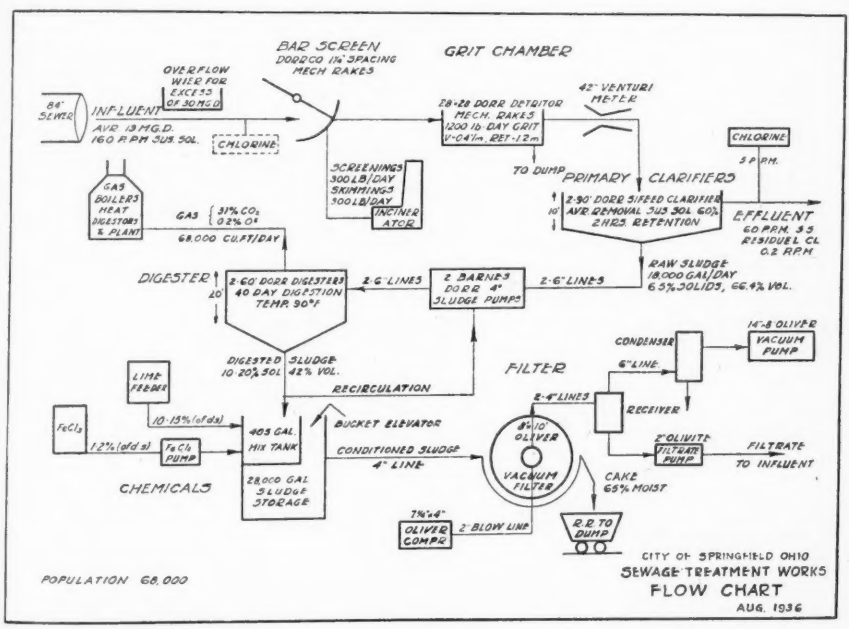
* Presented before the Tenth Annual Ohio Conference on Sewage Treatment, Columbus, Ohio, Oct. 2, 1936.

Sludge Filration

Historical.—Mechanical filtration of digested sludge has been studied extensively at Baltimore, Maryland. A paper published by Keefer and Cromwell (1) in 1932 aroused widespread comment and interest in this subject. Another paper from this same organization published by Genter (2) in 1934 threw considerable additional light on the subject.

Two cities in Ohio have also operated experimental plants for some time, namely, Columbus and Cleveland. As a result of this work both these cities are installing sludge filtration plants. From a recent tabulation by Fischer (3) Springfield is the only city in the country filtering digested primary sludge. Columbus is likewise listed in this tabulation and it is planned to filter digested sludge there.

Springfield started operations without any definite precedent of plant operation or operating data and consequently most of our work has been devoted to the smoothing out of operations. The greater part of the treatment proper should be considered experimental.



Plant Appurtenances.—A study of the flow sheet will disclose that the digested sludge is drawn by gravity from the digesters to a small sludge storage tank, from which it is elevated to the mixing tank by means of a bucket conveyor. Ferric chloride is fed to the mixing sludge, followed by application of lime. The time of mix varies directly with the output of the filter and the concentration of the sludge. The time varies from seven minutes on a thin sludge to fourteen minutes

on a heavy sludge. After mixing, the sludge is conveyed by pipe line to the reservoir of the filter where the filter picks it up, filters, dries and discharges it into cubic yard cars which are hauled to the dump or to a loading dock for final disposal.

Operation as Designed.—Operation was started October 29, 1935, using ferric chloride only and continued until November 7, 1935. We found that we could get an average rate of 6 lb. per sq. ft. per hour but had to feed 11 per cent ferric chloride to get these results.

During this time we were troubled with the liberation of excessive amounts of carbon dioxide which caused the sludge to foam and become very light so that it had to be mixed with water in order that it would flow through the pipe line to the filter. It was suggested that the sludge was over-digested, so several feet of sludge were drawn from the bottom of the digesters to a lagoon but this did not improve matters.

The costs of treatment were excessive as the following tabulation will indicate:

TABLE III

Ferric Chloride, @ $0.0217 per lb.	$4.77
Labor (3 men)	1.92
Filter cover	.20
Power	.40
Total cost per dry ton	$7.29

Laboratory experiments were started immediately, using ferric chloride and lime to see if results could not be improved. The laboratory tests looked so promising that we promptly made arrangements to feed lime in addition to ferric chloride. Generally speaking the results were most excellent and far exceeded our expectations. Filter rates were very high, averaging 13.7, 13.5 and 13.2 lb. per sq. ft. per hour for May, June and July. Costs were exceptionally low, as listed in Table IV, basis being per ton of dry solids.

TABLE IV

Chemicals	May	June	July
Ferric Chloride	$0.86	$0.87	$0.85
Hydrated Lime	0.90	0.95	1.45
Labor	0.84	0.91	0.96
Filter cover	0.06	0.06	0.06
Power	0.20	0.20	0.20
	$2.86	$2.99	$3.52

Costs are based on the same labor charges as used before—same rate for power per hour, $0.0217 per pound for ferric chloride and $0.005 per pound for hydrate of lime. We are now using a canton flannel cover on the filter at about one-fourth of the cost of wool covers.

General operating data covering the periods tabulated above are given in Tables V and VI.

TABLE V.—*Digested Sludge*

Month	pH	Avg. p.p.m. Total Alkalinity Methyl Orange	Per Ct. Solids	Per Ct. Volatile	Total Tons Filtered Dry Basis
May	7.7	4540	20.4	39.0	175
June	7.2	5260	21.0	39.4	122
July	7.1	4260	13.5	43.0	140

TABLE VI.—*Chemical dosage per cent of dry solids*

Month	Ferric Chloride	Hydrate of Lime
May	1.98	9.1
June	2.01	9.5
July	1.94	14.5

Control of Treatment.—To date we have not been able to determine upon a definite or accurate chemical test for controlling the chemical treatment. A good part of the control depends upon observation of the character of the mat on the filter, similar to the practice in coagulation of water. Furthermore, a close check is maintained upon the rate of production and alkalinities are run frequently upon the filtrate. We try to maintain a dry cake and a phenolphthalein alkalinity of from 2000 to 2500 p.p.m. in the filter effluent. Ferric chloride is fed by observation and frequent check on the amounts used. At all times the filtrate is very clear except for a faint cloudiness due to precipitated calcium carbonate. The average moisture content of the filter cake was 59.5, 58.8 and 63.4 per cent for May, June and July, respectively.

Results during the months of May and June were comparable in all respects but during the month of July all results were much poorer. Costs were greatly increased and rate of production was much lower. Reasons for this will be taken up later.

Study of Costs.—In the above tabulations of costs fixed charges were omitted and the lime used was hydrate at $10.00 per ton with 68 per cent available CaO. Pebble lime can be purchased for $8.00 per ton with 90 per cent available CaO. This will reduce the cost of treatment, for lime only, about 40 per cent. In a recent tabulation of operating data by Fischer (3) he indicates one man per filter whereas three are used at Springfield, one for operation of the filter proper and two to remove and dispose of the filter cake. Belt conveyors, etc. could be utilized for this final disposition of sludge thus materially lowering the cost of operation.

Keefer (4) in discussing the filtration of elutriated sludge at Baltimore, estimated the cost of filtration at $3.38 per ton of dry solids, when using ferric chloride. Of this amount about $1.13 per ton of dry solids are fixed charges leaving a net cost for chemicals, labor, power, etc., of $2.25 per ton of dry solids. It would thus appear that by using pebble lime fed from a chemical feeder and ferric chloride the

costs of filtering sludge at Springfield during May and June would be as cheap or nearly so as the estimated costs for Baltimore filtering elutriated sludge.

It would be interesting to see a comparison of cost on installations of equal size.

We have used wool covers, 40 oz. canton flannel covers and 8 oz., 29 in. width duck covers on the filter, and plan to use an 8 oz. 40 in. width duck cover. The wool cover is unsuitable for sludge filtration when using lime, as wool is attacked by alkaline solutions.

The canton flannel cover has proven to be the best and about 200 tons of dry solids are filtered per cover. The duck covers hold up much better than the flannel but clog much more readily, yielding only about 140 tons. It is hoped that the looser weave duck cover will give better service than the canton flannel. The duck is about 25 per cent cheaper than the canton flannel. We can remove and replace a cover with a new one in about four hours using four men.

Considerable trouble was experienced in regulating the ferric chloride feed due to the manner in which this feeder is driven. The feeder is driven directly off the shaft operating the bucket elevator, the speed of which is regulated by a Reeves Variable Speed Transmission. When the Reeves setting is changed a decided change in the percentage of ferric chloride being fed is made. This causes overtreatment or undertreatment depending upon whether the bucket elevator is speeded up or slowed down. It is planned to separate these units and have an independent drive for the ferro feeder, setting of which will be controlled manually. Likewise, when the lime feeder is installed it will be independent of other units and manually controlled.

Another constant source of trouble is encountered when we are operating the filter, due to loss of gas pressure during withdrawals of sludge from the digesters which are of the fixed cover type.

Two suggestions are made that might be considered in future design: first that a gas holder be incorporated in the design of plants. This gas holder would act as a gas storage tank and by floating on the line would balance and equalize gas pressures Second, that a fairly large storage tank for holding digested sludge be provided in addition to the digesters. This extra tank need not be utilized for gas collection and would not necessarily have to be of the covered type. With the addition of this additional tank it is believed that a schedule of operation could be worked out wherein digested sludge could be drawn to this tank when primary sludge is being pumped and held in storage until filtration operations are started.

Another advantage of this method of operation would be the concentration of the digested sludge. The advantages of filtering a concentrated sludge will be taken up later.

A number of laboratory experiments were run which may be of interest. Computations were made calculating the amounts of lime required to react with the calcium and ammonium bicarbonate present in the sludge plus the amount required to furnish the hydroxyl ion for

precipitating the iron. A figure was arrived at which was considerably below the amount of lime required in actual operation. In the computations no allowances were made for the amount of hydroxyl ions liberated by the reaction between the ammonium bicarbonate and the lime. The following reaction takes place:

$$NH_4HCO_3 + Ca(OH)_2 = NH_4OH + CaCO_3 + H_2O$$

The above noted reaction will account for the strong odor of ammonia about the filter when operating. On large installations using this process and where a number of filters are being operated in one room it might prove advisable to provide for additional ventilation; probably suction fans would be the solution.

Likewise, no attempt was made to compute the amounts of lime that might be required to break down ammonium carbamate or used in forming substitution compounds with the various amino-ammonia-nitrogen compounds.

In sludge conditioning it is believed a softening action takes place and that the calcium and magnesium salts present are precipitated as insoluble carbonates within the limits of solubility. Therefore, it would appear that if lime was first added to the sludge in proper amounts and a long contact period provided, that considerable lime could be saved over the present mode of operation where a large excess of lime is used and a very short contact period is provided. After the first lime had completed its work it was planned to add the required ferric chloride followed by additional lime and a short mix.

With the above procedure in mind, 2000 gm. samples of sludge were treated with varying doses of lime for varying contact periods. Results obtained were very unsatisfactory. Because of the formation of ammonium hydroxide it was impossible to reduce the total methyl orange alkalinity to below about 2000 p.p.m. As the original sludge had a total alkalinity of 5000 p.p.m. this would indicate that about 2800 to 2900 p.p.m. of the original alkalinity was due to calcium and magnesium bicarbonates, the balance being ammonium salts, presumably the bicarbonate.

Some of this pretreated sludge was treated with ferric chloride and additional lime, given a rapid mix and filtered using a Büchner funnel and following the technic described in Genter's (2) article. It was found that the sludge filtered very poorly, and even when using amounts of chemicals in excess of those required in regular procedure we could not get a good filtering sludge. Two theories are advanced for this:

First, many organic chemical reactions are slow and require considerable time for their completion. In some cases this may be extended into days. It is believed that during the long contact period provided in pretreatment with lime some reactions were started or completed that did not have time to take place when using a "flash" mix. Likewise, it is possible that some of the end products formed from these reactions would retard or hinder coagulation. The above theory may explain why no saving in lime could be effected through pretreatment.

Second, it is possible that some of the lyophobic colloids are converted to lyophylic colloids, which would account for the sludge being more difficult to condition. This change in the nature of the colloids is aided or accelerated in basic solutions, which of course is what we were handling.

While the results of the experiments are negative in character they have been incorporated in this paper so that future experimenters will have the benefit of our experience. Likewise, to the best of my knowledge this is the first time this procedure has been tried and it is possible that the idea still possesses merit and that some important point has been overlooked in our investigation.

The following are some of the variables we have encountered in operating the filter.

(*A*) Digested Sludge. Chemical
1. Hydrogen ion concentration
2. Solid content
3. Variations in alkalinity
4. Variations in amino-ammonia-nitrogen
5. Degree of digestion (measured by volatile matter)
6. Variations in sludge due to seasonal change

(*B*) Variations in treatment
1. Ferric chloride
2. Lime
3. Mixing time

(*C*) Filter Proper
1. Drum speed
2. Type and condition of cover
3. Mechanical difficulties, breakdown, etc.
4. Vacuum
5. Size of pipe lines both leading to and from the filter

(*D*) Personal
1. Changes in treatment
2. Lack of proper control

To elaborate on some of these variables:

Under "*B*," ferric chloride, the tendency is to increase the feed of this chemical whenever we start receiving poor results. I am of the opinion that as a whole the ferric chloride feed has been too high, as we have occasionally obtained excellent results with about 1 per cent of ferric chloride. The same is true of lime feeds.

Under "*C*," drum speed, we have operated from rates of 50 to 170 seconds per revolution of drum. We find that by operating at a higher speed we get a much thinner cake but a greater production per hour. Likewise, when the filter starts to smear the tendency is to operate the drum at a slower rate.

Filter Cover.—This is the most variable of the factors listed. First we have tried out three different types of covers and second, we find that as soon as the cover starts to "clog," due to incrustation with lime, our filter rates drop off very rapidly. Increasing the chemical treat-

ment does not help. At this time we have arbitrarily adopted the program that as soon as our filter rate drops to 10 lb. per sq. ft. of filter area we change covers. A new cover is much cheaper than additional chemicals and labor.

To indicate the tremendous effect of some of these variables, the following example is quoted:

On May 19th, the filter was operated 5½ hours drawing sludge from No. 2 digester. The average rate was 10 lb. per sq. ft. per hour at a chemical cost of $1.66 per ton of dry solids. A new canton flannel cover was installed on the following day and on the 21st of May the filter was again operated from the same digester. Results were very satisfactory. The average rate of filtration for 6.5 hours was 15.9 lb. per hour at a chemical cost of $1.60 per ton of dry solids. Chemical analyses of the digested sludges for these two days were practically the same, being

	Per Ct. Solids	Per Ct. Volatile
May 19th	23.1	38.4
May 20th	22.9	37.8

From the foregoing it is obvious that a great deal of discretion must be exercised in drawing conclusions from the work to date.

Appended are three graphs prepared from hand picked results. By this we mean days were selected covering certain ranges, *i.e.*, concentration of sludge, rates of filtration and costs.

When the filtering processes were apparently operating at maximum efficiency, the points on the graphs showed the same days in all cases, so that they are comparable throughout.

From a study of Fig. 1, it would appear that as the sludge becomes more concentrated the rate of production increases, with a very sharp break between 17 and 19 per cent solids. It also is of interest to note that as the percentage of solids increases the percentage of volatile matter decreases. Both the high solid content and the low volatile content indicate more complete digestion. To date the opinion generally held has been the exact opposite, namely, that the more completely digested the sludge, the more difficult it was to filter. Certainly this is not true of the sludge at Springfield.

Figures 2 and 3 are plotted both on a dry solids basis and on the total weights of sludge. It has been customary in all past data to report results on the basis of dry solids. Obviously this method of figuring costs and chemical dosage ignores completely the liquid surrounding the sludge particles and any effect on the treatment this liquid may have. For convenience in this discussion we will call this liquid the vehicle.

Curves in Figs. 2 and 3 naturally have the same general characteristics and it is interesting to note that in all four we get a sharply reversed curve. This is decidedly more pronounced with the wet sludge and persists a little longer than with the dry sludge.

From a study of the dry solids curves, it appears that lowest chemical costs are obtained at a solid content of about 17 per cent and a filter rate of slightly over 14 lb. per sq. ft. per hour. However, it should be noted when studying the dry solids curve that the curve tends to flatten

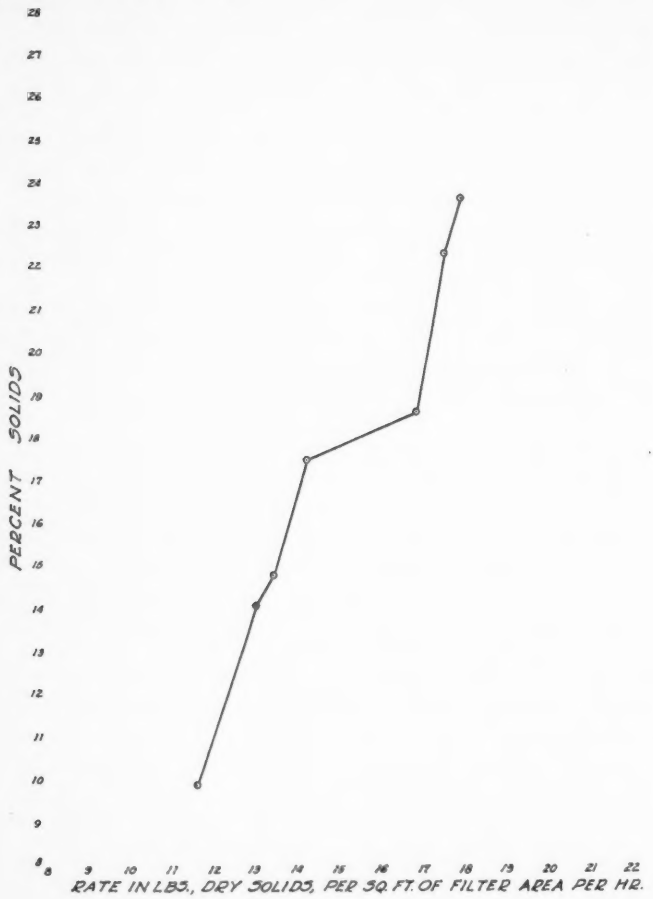


FIG. 1.

out and that there is not a great difference in chemical costs between the ranges of 14 and 23 per cent solids and filter rates between 14 and 18 lb. per sq. ft. per hour.

A study of the wet curve indicates that the lowest chemical costs are obtained at approximately the same points as in the dry solids curve. This point would appear to be optimum conditions as far as effectiveness of coagulation is concerned. However, in both wet curves after the reversal takes place the trend seems to persist and between the ranges of 14 and 23 per cent solids and filter rates between 14 and 18 lb. per hour, the cost continues to increase and there is a wide divergence

between the cost at the start of reversal and the last costs plotted. It will be noted that these curves again tend to reverse and go toward lower cost. However, this second reversal is so slight that it could be accounted for by some of the other variables.

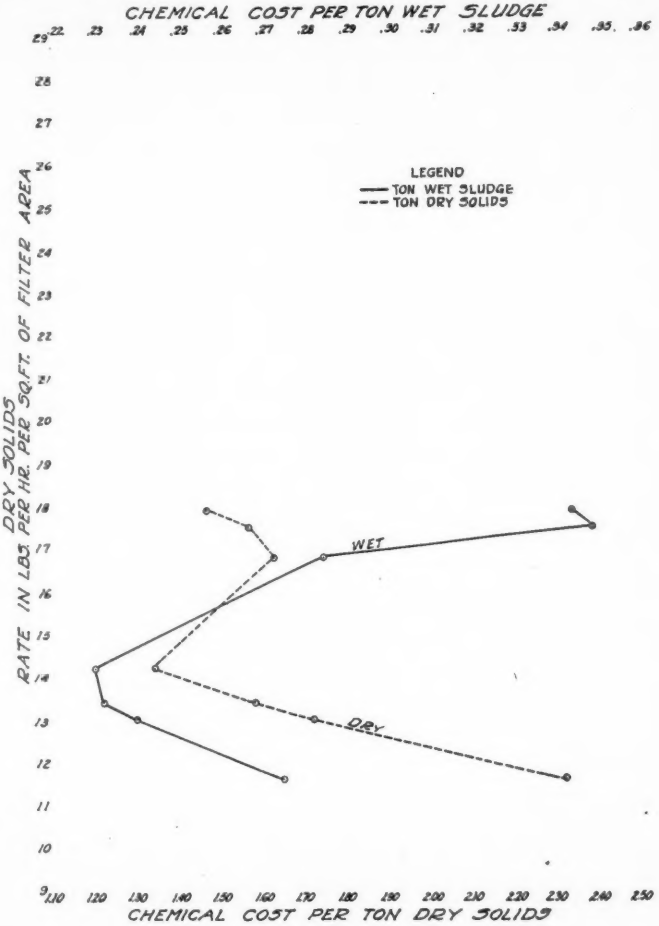

CHEMICAL COST PER TON WET SLUDGE
.22 .23 .24 .25 .26 .27 .28 .29 .30 .31 .32 .33 .34 .35 .36
LEGEND
TON WET SLUDGE
TON DRY SOLIDS
RATE IN LBS. DRY SOLIDS PER HR. PER SQ.FT. OF FILTER AREA
WET
DRY
110 120 130 140 150 160 170 180 190 200 210 220 230 240 250
CHEMICAL COST PER TON DRY SOLIDS

FIG. 2.

Genter's work (2) at Baltimore, proves that on the sludge used by him, most of the coagulants were absorbed by the amino- ammonia-nitrogen end products of digestion. A study of the curves obtained at Springfield seems to indicate that this was not the case on Springfield sludge. We have not determined the amino-ammonia-nitrogen content of the sludge but it would seem reasonable that if the other constituents were comparable and that digestion was completed to about the same degree, that the amino-ammonia-nitrogen end products should be produced in comparable amounts. On this assumption a

study of Figs. 2 and 3 discloses some very interesting points. First it would seem that as the sludge becomes more concentrated in solid content the amounts of amino-ammonia-nitrogen salts present would become less in proportion to the solid content. As these compounds

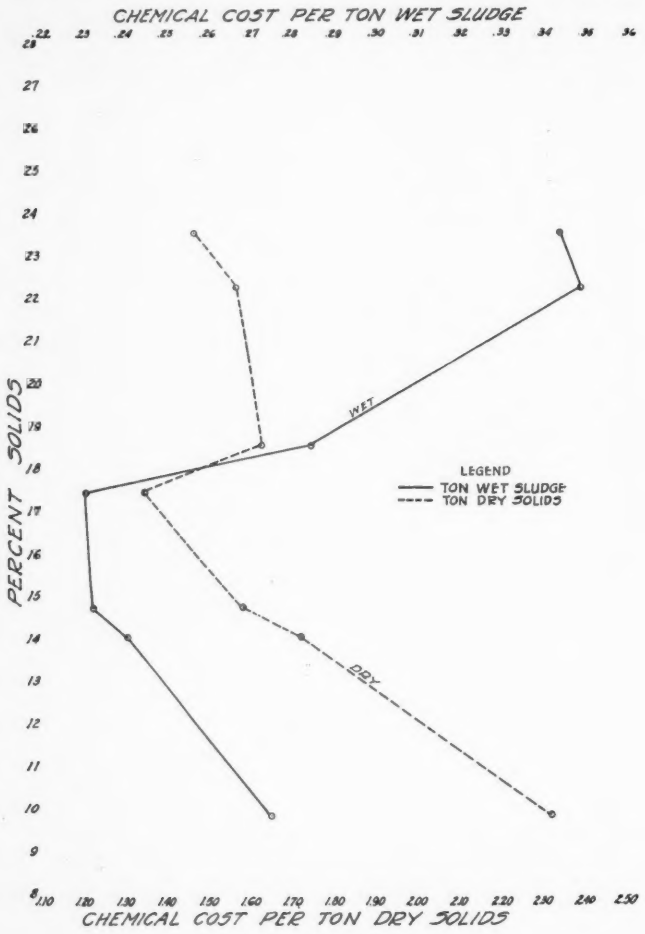


FIG. 3.

are soluble and are contained in the vehicle therefore we should require less coagulant per pound of dry solids as the sludge becomes more dense. A study of the dry solid curves bears out this contention up to a certain point, namely, between the ranges of 9.8 and 17.4 per cent solids. After that a reversal occurs and the curve flattens out. Picking the three points 14.7, 18.5 and 22.2 per cent, there is only $0.06 difference in chemical cost per ton of dry solids, whereas we should expect a considerable difference if the vehicle were absorbing the coagulant.

A study of the wet curves likewise indicates that between certain points the vehicle appears to absorb the coagulant. This is not nearly so pronounced as in the dry curve and apparently we reach optimum conditions a little sooner on the wet basis. From the optimum and reversal points the wet curve follows the solid content of the sludge very closely thus indicating that it is the sludge proper and not the vehicle that is using the coagulant. Chemical cost mounts rapidly in this part of the curve wherein the sludge becomes more dense.

The explanation for this curve reversal may be that up to a certain point in Springfield sludge the amino-ammonia-nitrogen compounds play an important part in the conditioning of our sludge. After this point is reached the colloidal sludge particles themselves assume the major role and thereafter are the controlling constituent with which we have to deal.

Genter (2) and Keefer and Kratz (5) have noted that when sludge is elutriated, the elutriates contain from 260 to 1360 p.p.m. of suspended matter. The latter value was obtained when a mixture of digested primary and secondary sludges were subjected to elutriation. Genter (2) considers the washing out of any colloids during the process of elutriation as of minor importance and has apparently proved his point; however, many of us who have had experience in the coagulation and treatment of water are well aware that the suspended matter or turbidity are not criteria of the amounts of coagulants required to produce good flocculation. Many times a water with high turbidity will require less coagulant than a water containing relatively small amounts of suspended matter but containing collodial coloring matter or other elements that retard coagulation. This would appear to be a point worthy of further investigation.

If our observations are correct, that the more concentrated and better digested the sludges become the lower the costs and the higher the rates at which the sludge may be filtered, it would seem desirable to have sufficient digester capacity to allow for fairly complete digestion and possibly some concentration of solids in the digester proper, or in a separate thickener.

Conclusion

From observations and experiences in operating an Oliver vacuum filter on digested primary sludge at Springfield, Ohio, for a period of about eleven months, during which time a total of over 900 tons (dry basis) of sludge were filtered, the following tentative conclusions and theories have been advanced in this progress report:

1. Costs are high and filter rates are low when ferric chloride only is used in conditioning the sludge at Springfield. The combination of lime and ferric chloride is greatly to be preferred.

2. To date canton flannel covers for the filter give the best results.

3. Gas holders should be used when operating digesters with fixed covers.

4. An adequate sludge storage tank located between the digesters

and the filtering equipment is advocated so as to completely divorce sludge filtering operations from primary sludge pumping.

5. It has been demonstrated that pretreatment with lime does not effect any saving of chemicals and produces sludges that do not filter well.

6. A study of Fig. 1 indicates that rates of filtration are directly influenced by the solid content of the digested sludge and that the higher the solid content the higher the rate of filtration.

7. Apparently, completely digested sludges are more amenable to conditioning and filtration than are semi-digested sludges.

8. Digesters should be of sufficient capacity to produce well digested sludge. Thickening devices or digested sludge storage may be utilized for the concentration of the digested sludge.

9. It is advocated that computations of both costs and chemical treatment be made on both the dry basis and the wet basis in future work.

10. Figures 2 and 3 indicate that the lowest chemical cost of treatment is obtained at about 17 per cent solids and a filter rate of about 14 pounds of dry solids per square foot of filter area per hour.

11. The curves in Figs. 2 and 3 are of the reverse type, which is more pronounced in the wet curves. One section of these curves may be explained by the theory of amino-ammonia-nitrogen in the vehicle and the other section by the theory of coagulation of colloids.

A question has been raised many times regarding the capacity of these filters for design data. In the past this figure has been between 4 and 5 lb. dry solids per sq. ft. of filter area per hour. In the light of experiences at Springfield, we believe this figure, for this type of sludge, could be at least doubled. Also the question has been raised as to how small a plant could use this method for sludge disposal. This, of course, would depend upon many factors, the most important of which would be the type of personnel engaged in operating the device. To date our experience indicates that these operations require constant and close supervision of a fairly high type. Generally speaking, I am of the opinion that at present this process should be confined to the larger plants with capacities of 10 m.g.d. and up.

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SYMPOSIUM ON SLUDGE DISPOSAL PRACTICES

The Canadian Institute on Sewage and Sanitation
Toronto, Ontario, October 1, 1936

SLUDGE DIGESTION

By Grant R. Jack

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Introduction

The symposium on "Sludge Disposal Practices," which was chosen by your Committee as the nucleus of interest for discussion at this convention, constitutes, I believe, an important phase in sewage disposal which at the present time is requiring the concentrated efforts of all engineers interested in this vitally important process.

The three papers to be presented under this title are very closely allied with each other: my subject is "Sludge Digestion."

In Ontario we have today approximately seventy-five sewage disposal plants which serve a total population of about 1,350,000 persons. Some of these plants have been in use for over 30 years with the majority having been constructed during the last 15 years, and in most cases, I venture to say, enterprising councils and engineers have seen fit to carry out improvements and additions in an effort to keep up with modern practice and at the same time to contribute in no small way towards the elimination of difficulties which are continually being encountered.

History

In recent years the question of sludge disposal has been attacked with vigor, many improvements have been made, but until a process is evolved whereby sludge disposal can be effected with a minimum of cost we cannot say that the problem has been solved.

Nearly fifty per cent of the disposal plants in Ontario employ the activated sludge process, including sludge digestion. Prior to the introduction of the activated sludge system in sewage treatment, sludge digestion did not occupy the prominent position it does today, due partially to the fact that sludge was discharged directly on open drying beds in a fairly inoffensive condition. This does not mean that the old systems had a high standard of efficiency and were trouble-free, but rather that the health officials, engineers and the public of today will not tolerate the many nuisances and inconveniences created by the old type of disposal, and control of such processes was not possible without drastic changes. Early methods of sludge digestion consisted primarily of a type of two-stage process, similar to that employed in a septic tank, whereby the digestion is effected while the solids are in contact with the flowing sewage. An improvement on this process was brought about by the introduction of the two-story settling tank in

which the solids settling from sewage in the sedimentation compartment are finally digested in another compartment of the same tank. While considerable improvement was made by this method it was found to be too expensive, yet it was a step towards the desired end.

With the introduction of the activated sludge system each process in the treatment of sewage became individual. Manipulation and control of the various stages was made possible and more practicable, and the construction of individual units was also more desirable and economical.

Types of Digestors

The selection of one of two types of digestion tank is possible, each having its own merits. These are the gravity type of tank, usually square or rectangular in shape, in which the digested sludge is concentrated at the outlet by gravity due to the conical or sloping shape of the bottom, and the circular tank which employs mechanical scrapers to assist in the withdrawal of sludge.

Opinions differ considerably as to the selection of one of these types of tanks for digestion purposes. In East York we have two sewage treatment plants, both of the activated sludge type, which handle one hundred per cent domestic sewage; at the Todmorden plant the digestion tanks are all of the gravity type while at the Danforth Park plant both the gravity and mechanical types of tanks are employed. From my observations of these two types I believe that for the average plant the gravity type of tank will give satisfactory results and, of course, is more economical in all ways.

Sludge Preparing and Conditioning

Usually digestion tanks meet their first obstacles just after the tank is placed in service. The correct way to start digestion is to fill the tank partially with actively digesting sludge from some other tank, maintain the temperature to which the seeding organisms are accustomed, and fill the tank very slowly with fresh material, each day adding perhaps about ten per cent of the volume of solids then in the tank. If, however, the tank is to be started without any seeding material, it becomes necessary to generate seeding material from the raw sludge, which, of course, takes time and care, and may take a month to accomplish. It is good practice during this initial sludge ripening to endeavor to control the balance between acidity and alkalinity, and daily tests should be taken to determine the pH value and thus establish an alkaline condition. The general standard for pH is recognized at about 7.1 to 7.5. Values below 7.1 indicate an acid condition which requires correction by the addition of lime, the quantity to be added depending on the condition of the sludge and the capacity of the tank.

The reason for maintaining the pH between 7.1 and 7.5 is that the bacteria which cause the digestion of the sludge work more favorably in this range than in any other and consequently digestion will be more rapid and incidentally more gas will be given off under these conditions.

Sludge Heating

It is generally understood that digestion is a biologically activated process and that decomposition which is completed by the organisms of decay is effected most rapidly at temperatures which are considerably above the average temperatures, particularly in Canada and the northern United States. This belief is based on studies which showed that low temperatures retarded digestion and therefore necessitated larger storage facilities for sludge. The result of these observations was that a means for maintaining a suitable and even temperature in the tanks had to be evolved. Early experiments were first tried by the injection of steam and hot water as a means of heating the sludge, and I believe that in Germany this method has met with some success. A later method, and one which is now generally accepted in this continent as more practical, is the installation of hot water heating coils in the digestion tanks. This type of heating requires less heat, is quicker, and also gives greater gas production, the latter point being due probably to the fact that with the injection type of heating a certain amount of dilution is caused, which in turn allows solids to be carried away in the overflow before they have given off their full quota of gas.

Opinions differ somewhat as to the correct temperature required to be maintained in the tanks. At the new sewage plant constructed at Rome, N. Y., Mr. H. W. Taylor concluded, after extensive study, that the optimum temperature for sludge digestion appeared to be between 78 and 84 degrees F. and that high temperatures up to 90 degrees F. were not favorable to gas production. On the other hand, a committee of the American Society of Civil Engineers reported that a desirable temperature would be between 80 and 100 degrees F. I do not think that it is possible to determine a correct working temperature for any specific plant, as there are too many elements to be considered.

Experiments reveal that the placing of heating coils in the digestion tanks about three feet above the floor of the tanks gives the best results. In East York we followed this practice and, after experimenting with the temperatures, found that while a temperature above 80 degrees F. was desirable and gave better gas production, it did not warrant the additional expenditure on fuel, as the increase in gas content was not sufficient to dispense entirely with the coal heating auxiliary.

Gas Collecting and Burning

Following the recognition of heated digestion tanks as a medium for reducing the retention period, the utilization of the gas given off by the sludge was studied. This gas, of which about 75 per cent is the combustible gas methane, had been long recognized as valuable, and facilities for controlling and collecting it had to be perfected. Harnessing the gas for use is important when we realize that it has been successfully applied for use as fuel in gas engines, pumps, heating buildings, refrigeration, and, as we do in East York, contributing as an auxiliary heating agent for the digestion tanks.

The collection of the gases presented some difficulties and many different ideas were tried out, but at the present time two popular methods are recognized. These are the digestion tank with the floating cover, very similar in operation to the gasometer, and the tank with a solid concrete top with gas domes. In East York all digestion tanks have concrete roofs with gas domes built in for the accumulation of the gases. I would point out here that it is essential that extreme care be given to construction details to ensure gas-tight construction, particularly where additions are being made for the utilization of gas.

The ultimate volume of gas produced by the digestion of sludge varies directly with the nature of the solids digested. However, experiments show that the complete digestion of a pound of volatile fresh solids will produce between 8 and 12 cu. ft. of gas and likewise the production of gas on a per capita basis will probably average about 0.4 to 0.6 cu. ft. which might be considered normal. In East York, where the sewage is entirely domestic, our gas production is somewhat limited.

East York—Todmorden Plant

Population served—20,000.
Capacity—1,750,000.
Average daily flow of sewage (period April 1935 to April 1936)—810,600 gal.
Digestion capacity—224,000 gal.
Average daily run of sewage to digestors—26,700 gal.
Average daily run of digested sludge to drying beds—1,550 gal.
Average daily amount of dry sludge removed—40 cu. ft.
Average daily gas production—2,370 cu. ft.

Cost of heating digestion tanks,
Fuel $318.00, Power $76.00, Labor $300.00; total $694.00.
Cost of pumping sludge from digestors to drying beds,
Power only, $127.00.
Cost of heating drying beds and sludge removal,
Fuel $218.00, Power $75.00, Labor $1,200.00; total $1,493.00.

Drying bed (1929)—one bed 100 ft. by 40 ft., cost $6,500.00.
Drying beds (1932)—constructing 2 beds and altering existing bed, $9,000.00.
Drying bed (1932)—drying bed heating plant, $5,300.00.
Drying bed, present area 100 ft. by 120 ft.—12,000 sq. ft.

Drying

The final disposal of sludge has been studied intensively in recent years and efforts are constantly being directed to produce a cheap and reliable process. At this point I feel that I am trespassing on some of the territory to be covered by subsequent speakers, but I cannot conclude without some reference to the question of sludge drying.

The disposal of sludge is being accomplished briefly in the following ways:

1. Sludge undigested and dried on open beds.
2. Sludge digested and dried on open beds.
3. Sludge undigested and dried on covered beds.
4. Sludge digested and dried on covered beds.
5. Sludge dewatering equipment such as belt or rotary vacuum filters, pressure filters, centrifuges and spraying in heated towers, and finally by incineration.

The evolution of sludge digestion has been covered briefly and I do not intend to propound the many advantages of mechanical dewatering but would like to prescribe some of the essentials which produce fairly efficient results in sludge drying as it is practiced generally today.

Sludge Drying Essentials

Sludge drying consists essentially of two features "draining" and "evaporation" and the accomplishment of these in a speedy and satisfactory manner has during the past few years created some important theories on this subject, and we have seen some radical changes take place during the past few years.

Principles of Sludge Bed

First effective efforts to reduce the moisture content in sludge were confined to the open type of filter bed, which employed an arterial system of drains in conjunction with a filter bed of stone and coarse sand. This did not prove satisfactory because of difficulties introduced by prevailing weather conditions and also the fact that completely undigested sludge would give off odors which were very offensive.

This open filter bed is being quickly superseded by the glass-covered drying bed and considerable improvement has been noted.

Digested sludge contains a quantity of gas which brings the solids to the surface when the sludge has just been placed on the drying beds, and the lower strata of residue water percolate through the filter bed of sand, allowing the solids to settle down and thus form a spongy mat. This process may be termed "draining" and is controlled chiefly by the physical construction of the bed and by the character of the sludge. Following the draining of the sludge the drying process is completed by "evaporation," which in turn is correlated with the constructional features of the drying bed enclosure, in conjunction with climatological factors.

While no radical changes could be brought about to improve the draining ability of the drying beds it has been possible to improve considerably on the means of evaporation; thus entered the era of the glass-covered drying bed. The claims put forward on behalf of the covered bed were that they would facilitate drying by protection from

unfavorable weather conditions, assist in the control of odors and reduce considerably the drying area previously required.

In East York, when the disposal plants were first constructed, the open type of sludge bed was used but these were later replaced by the glass-covered drying beds which have in turn been altered considerably to improve drying facilities. The early thought behind the adoption of the glass-covered bed was the protection given from adverse weather conditions, and further, that the glass-covered structure assimilated heat from the sun. In order to continue the drying all year round a heating system was installed.

Covered Drying Bed Requirements

Over a period of time, however, it was observed that the system of ventilation was indeed a very important factor in contributing to the efficiency of the glass-covered bed, and with proof of this, drastic changes in the ventilation of the houses were brought about. In the first place, the early type of covered bed was not built so that full advantage could be taken of induced air currents. The masonry of the side and end walls of the building was built with the glass structure about four feet above the drying elevation and the sash in this case hinged outwards. The principle of drying was, I believe, based on the theory that air entering the sash opening outward on the sides and ends, assisted to force out the partially moisture-laden air through the ventilation in the ridge of the structure.

This theory was upset when it was found by actual test that if the air was admitted as low as possible, compared with the surface of the sludge, its ability to collect moisture was greatly advanced. Changes along these lines were carried out, the walls were cut down to approximately 18 inches above the sludge level and all sash made to open inward from the bottom.

Similar thought was given to the heating system, which first consisted of pipe coils. These did not, however, give best results because of considerable waste of heat and the inability to concentrate heat on the sludge. After considering several schemes for the concentration of heat upon the sludge to induce evaporation, we decided on the installation of unit heaters, one suspended over each drying area. Our experiences with this installation have amply justified the changes and expenditures made.

The depth of wet sludge applied to the drying area depends on local characteristics and must be determined at each plant by study. It is, however, obvious that the lesser depth of sludge will dry more quickly. Sludge that is ready for placing on the drying beds contains between 97 and 98.5 per cent moisture and by actual practice it has been found that it cannot be removed until the moisture content has been reduced to at least 75 per cent. Sludge which contains less than 65 per cent of moisture may be classed as being in a positive "dry" condition.

Facilities for removing the dry sludge are available in numerous

forms and possibly the most convenient is by means of a mono rail with chain hoisted hoppers.

Mechanical Sludge Dewatering

The mechanical dewatering of sludge is today being watched with considerable interest. Several types of machines are available and the possibilities of their application to sludge dewatering will, when a higher stage of efficiency is reached, revolutionize the sewage treatment process.

At the Danforth sewage plant, in 1934, the Canadian Locomotive Co. conducted extensive experiments with a view to perfecting a vacuum type of sludge dewatering machine which they had developed. The experiments, which were also reviewed by this Association, brought forth some very conclusive results. Briefly, the machine, which employed a vacuum belt, is designed for daily use by the dewatering of the settled sludge direct from the settling tanks or clarifiers which comprise the first stage of sedimentation. The settled sludge was conditioned to induce coagulation by the addition of ferric chloride. The final results showed that sludge with an initial moisture content of about 98 per cent was reduced to an average of 84 per cent. Some conclusions regarding the adoption of any dewatering machine for general use are that its operation will require an efficiently trained operator and that it must be operated on a set daily schedule to avoid overloading the clarifiers or settling tanks.

The average small sewage plant without this process does not demand such careful attention, other than operating on a 24-hour schedule, and its operators, although not requiring any particular training, must of necessity thoroughly understand the requirements and functioning of the various units. By the foregoing, I do not infer that any sewage treatment plant operator can operate efficiently without some background. The standard of requirement should be high and should be governed to some extent by the type of plant being operated. Perhaps the chief advantage in mechanical dewatering will be the elimination of digestion tanks, etc., and heated drying beds which with all their appurtenances occupy considerable space, necessitate a large capital expenditure and are expensive to operate and maintain.

Incineration

Engineers and municipal officials are watching with interest the possibilities of incineration, especially where this can be co-operated with destruction of raw garbage. This combination no doubt will prove satisfactory to large municipalities; however, I am of the opinion that for the normal small sewage plant, sludge digestion will continue to serve efficiently and possibly more economically.

VACUUM FILTRATION

By James F. MacLaren

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The science of sewage treatment and sludge disposal has made marked advances in the last few years. New methods of treatment and new devices have been introduced. Never before has there been such sustained activity in the field of experiment and research. Incineration of sludge, until recently in the experimental stage, is today an accomplished fact.

Not the least of the contributing factors to recent progress has been the vacuum filter and its adaptation to the problem of dewatering sewage sludges after conditioning with chemicals. The process is now successfully practised in many plants. Milwaukee adopted this means of dewatering activated sludge in 1922, and while other plants adopted the process it was confined for some time thereafter to dealing with activated sludge, owing largely to the high cost of chemicals. In the last five years, however, the process has spread until now practically every type of sewage sludge is being dewatered by vacuum filtration. The development has been largely a matter of determining the chemical or combination of chemicals most suited to the various types of sludges consistent with the cost of chemicals and other economical features.

The published works of Keefer, Genter, Mohlman and many others dealing with sludge conditioning and dewatering has made available to engineers and plant operators a fund of information and data which is invaluable.

The complex nature of sewage and the varied processes and degrees of treatment practised account largely for the various types of sludges and the many problems to be dealt with in the matter of sludge disposal. It must be borne in mind that methods employed at one plant with success may fail at other plants and what may be established as an economic practise, or method, in some instances may prove uneconomical or unjustified elsewhere. The more experience one gains the more one realizes the need for careful study of local conditions. The type of sewage, the degree of treatment required and justified, the location of existing sewage treatment plants, or of sites available in the case of new projects, and the facilities for final disposal of the sludge all are factors which have a major bearing on the type of treatment and methods of disposal, and thus on the design of plant and equipment.

In dealing with the matter of vacuum filtration one must bear in mind that filter capacities, chemical requirements and the moisture present in the filter cake differ according to the nature of the sludge handled. Lime and ferric chloride are generally used for conditioning raw sludges, except in the case of raw activated sludge, where ferric chloride alone is used. On digested sludges, combinations of lime and ferric chloride or ferric chloride, preceded by elutriation, are generally favored. The chemical or chemicals to be used is a matter meriting

careful study for each individual case. The superiority of ferric chloride as a sludge conditioner seems to be well established and its greater use in recent years has made it available at lower prices than was the case a few years ago.

To the writer's knowledge there are only three sewage treatment plants in Canada at the present time where vacuum filtration of sewage sludge is practised. These are York Township, Long Branch and London, all in Ontario. It is noteworthy that the filters installed at these plants are of different manufacture and also that in each case vacuum filtration has been adopted to replace, or at least to augment, sludge disposal methods previously employed. Winnipeg, Manitoba, has under construction treatment works that include vacuum filters.

In the case of the York Township and Long Branch plants, with which the writer has been closely associated, vacuum filtration has proved successful, not only from the standpoint of producing a sludge cake that is readily disposed of to farmers and gardeners in the vicinity as fertilizer and soil conditioner at a cost which is reasonable, but also, by dewatering and disposing of the sludge at these plants regularly, operation as a whole has been improved to the extent of higher removal of suspended solids and abatement of odour nuisances.

York Township

York Township was the first municipality in Canada to adopt vacuum filtration as a means for dewatering sewage sludge, and in fact can claim to be among the pioneers elsewhere. This plant was constructed in 1925 and at present treats an average sewage flow of 2½ Imp. m.g.d. from a population of approximately 65,000 persons. As at present operated, the plant consists of grit channels, coarse bar screens, aeration tanks and settling tanks. Owing to the low water consumption in York Township (about 35 gal. per capita per day) the sewage is high in suspended solids, the average being 500 p.p.m. An excellent paper by Mr. C. Chamberlain, the plant superintendent, was published in July, 1934. It gives full particulars relating to the sludge disposal problem with which they were faced and their experiences since installing the vacuum filters in 1930. It is worth noting here that the filters at York Township, which are of the rotary string discharge type, built by Filtration Engineers, Inc., were designed with the intention of using sulphuric acid and lime to condition the sludge. The cost of this treatment proved prohibitive and was replaced by macerated paper and lime, which in turn was discarded in favour of ferric chloride. Costs and data taken from Mr. Chamberlain's paper are repeated here because they serve to illustrate the versatility of the vacuum filter and also to illustrate the great saving effected at this plant by adopting ferric chloride for conditioning the sludge.

An advance in the contract price of ferric chloride for 1936 to $2.65 per 100 pounds (anhydrous) will increase the cost per ton of dry sludge from $4.90 to $5.19.

Cost of Chemicals per Ton of Dry Weight Sludge		Moisture in Filter Cake	pH of Filtrate	Capacity of Filter, Lbs. per Sq. Ft. per Hour—Dry Sludge Basis
Acid Lime Process				
1540 lbs. sulphuric acid @ 1¼¢	$19.25	80%	—	1½
3 tons lime liquor	3.00			
	$22.25			
Paper Pulp Process				
1700 lbs. paper @ $9.00 per ton	$ 7.90	78%	—	1¼
1 ton lime liquor	1.00			
Cost of macerating paper (labour and power)	5.20			
	$14.10			
Ferric Chloride				
196 lbs. $FeCl_3$ @ 2½¢	$ 4.90	82% to 84%	5.8 to 4.8	2

From these figures it will be noted that not only was a tremendous saving made by using ferric chloride but also the capacity of the filters was increased. It is only fair to note that these filters were designed to function under alkaline conditions, but for the past four years have been subject to the corrosive action of acid conditions. As a consequence certain piping has had to be replaced and there is evidence that other metal parts are being affected.

Further economies in the amount of ferric chloride used can be made at this plant by improved conditioning and in applying the chemical, but here, as elsewhere, money for any expenditure, no matter how justifiable, is difficult to obtain.

Long Branch

The village of Long Branch was faced with a sludge disposal and odor nuisance problem somewhat similar to that experienced by York Township. The treatment plant was designed some 12 years ago to treat a sewage flow of 500,000 Imp. gallons per day by the activated sludge process. At present it serves a population of about 5,600 persons and the sewage is almost wholly domestic in character. The proximity of the plant to surrounding dwellings made it the centre of numerous and justified complaints, as there was no means of disposing of the sludge except on open air drying beds. Finally, in the fall of 1934, the Department of Health issued a mandatory order to the village council for abatement of the nuisance. After giving the problem a great deal of study it was decided that mechanical dewatering of the waste activated sludge and disposing of the dewatered cake daily for fertilizer offered the most economical solution of the problem. It was realized that the installation of a vacuum filter, involving, as it must, the application and control of chemicals for conditioning the sludge,

in a small plant was somewhat hazardous owing to the lack of constant high-class supervision, but nevertheless it appeared to be the only solution of the problem without resorting to a prohibitive capital expenditure.

In July, 1935, an Oliver rotary vacuum filter was installed, and except for one or two unfortunate instances in which both the filter and the treatment plant were the victims of neglect, causes for complaint of odor have been greatly lessened. In fact, for nine months after the filter was placed in regular operation there was no complaint, in spite of the fact that people dwell within 75 yards on three sides of the plant.

The filter consists of a drum 3 ft. in diameter and 6 ft. long, with a filtering area of 56 square feet. The unit, which is most compact, containing, as it does, the filter with all auxiliary equipment, sludge mixing chamber and bucket elevator in one structural assembly, is of such overall dimensions as to allow it to be placed in the existing compressor building without any alterations or additions to the latter worth mentioning.

The auxiliary units, assembled with the filter proper, consist of vacuum receiver, vacuum pump, filtrate pump and air compressor. The filter and all auxiliaries are driven from one 7½ H.P. motor, which is suspended beneath the filter tank platform. Through the medium of a Reeves drive the speed of rotation of the filter drum can be adjusted between ¼ and 1 r.p.m.

In addition to the filter unit a motor-driven single acting diaphragm sludge pump, having an adjustable capacity of from 12½ to 35 g.p.m., is installed. Also, a lead-lined chemical solution tank and solution feed controller were supplied with the filter.

When the filter was first placed in operation difficulty was experienced in obtaining and maintaining waste sludge thick enough to produce a proper sludge cake. Some minor changes were made in the return and waste sludge piping by reason of which sludge could be drawn directly from the cone of one clarifier tank. Operating in this manner sludge concentrated to 2¼ to 2¾ per cent solids is often obtained and seldom is the concentration less than 1½ per cent.

By withdrawing sludge by pumping at a moderate rate the sludge blanket in the clarifier tank can be lowered almost to the tank floor without dilution of the concentrated sludge. This is not the case when using the air lifts, which are of too large capacity and are difficult to adjust.

No record of daily performance is kept at this plant but from time to time tests have been conducted over short periods, which reveal filter outputs of 1.75 to 2.5 pounds dry solids per square foot per hour, 79 per cent to 84 per cent moisture in dewatered cake, and chemical consumption of 6 to 8½ pounds $FeCl_3$ per 100 pounds dry solids in sludge as fed.

That filter performance is greatly affected by the condition and

solids content of the activated sludge, as evidenced by the following records of tests:

Date of Test	Duration	Sludge Withdrawn			Ferric Chloride		Filter Output		pH of Filtrate	Condition of Waste Sludge (Visual)
		Gals.	% Dry Solids	Lbs. Dry Wt.	Lbs. $FeCl_3$ Added	Lbs. $FeCl_3$ per 100 Lbs. Sludge (Dry)	Lbs. Dry Solids per Sq. Ft. per Hour	% Moisture in Cake		
Jan. 27/36	1 hr.	500	1.44	72	6.24	8.67	1.49	86.1		Poor—near septic
Jan. 29/36	6 hrs.	3,075	1.63	501.2	45.39	9.06	1.75	82.8		Poor color
May 23/36	7 hrs. 9 min.	4,087	2.56	1,048	73.4	7.0	2.67	83.66	5.4–5.6	Excellent

Experience at Long Branch has demonstrated that, as far as the filter is concerned, ordinary intelligence is all that is required to operate it. The appearance and character of the sludge cake and the appearance of the filtrate are the operator's guide as to what dosage of ferric chloride is required.

The solution is fed by gravity through an inexpensive and simple feeder which maintains a constant head on a small nozzle. The rate of application can be altered by raising or lowering the nozzle.

A manometer against a graduated scale provides a means for setting the rate. The range of adjustment, together with various sized nozzles, allows a variation up to 300 c.c. of solution per minute.

Ferric chloride is applied to the sludge as the latter enters the mixing tanks. The mixture spills over a weir and passes through the tank, which is baffled, and at 10 inches of depth provides about 5 minutes mixing, after which the conditioned sludge is elevated by bucket conveyor into the filter tank. An oscillating paddle describes an arc beneath the filter drum and prevents separation of the sludge in the filter tank.

The sludge cake is carried outside the building by a horizontal conveyor belt and dumped on to a paved area which is covered in to afford protection from the weather. From 2½ to 3½ cubic yards of dewatered cake is produced per day and is shovelled into a truck each afternoon, at the end of the day's run, and hauled away to farms. To date one man has taken all the sludge, for which the village makes no charge, and this arrangement has proved highly satisfactory.

The installation of the filter at Long Branch has not required any

more labor at the plant than formerly, and consequently the costs of plant operation (exclusive of depreciation and carrying charges) are increased only by the amount of chemical, power and incidentals required to condition the sludge and operate the filter. These costs over a six months' period of operation were as follows:

7,000 lbs. $FeCl_3$ at \$4.75 per 100 lbs.	\$332.50
Electric power and light	85.56
One filter blanket	13.30
Grease and oil	4.50
Total	\$435.86

The estimated weight of dry solids in the sludge disposed of during this period is 50 tons, on which basis the costs amount to \$8.72 per ton (dry basis).

The contract price of the filter installed complete with all auxiliary equipment and sludge pump was \$7,110.

Ferric Chloride

At Long Branch ferric chloride must of necessity be purchased in 10-gal. glass carboys and delivered to the plant by truck. This makes the cost of chemicals quite high as compared with York Township which plant is fortunately situated near enough to a railway siding to enable deliveries to be made by tank car. The price per 100 lbs. of ferric chloride (anhydrous) to Long Branch is \$4.75 and to York Township \$2.65. From a comparison of these figures it will be seen that it is very important, particularly where chemicals are to be used in fairly large quantities, to have railway facilities close to the plant. The ferric chloride solution at present used at each of these plants is manufactured by Canadian Industries Limited, at Windsor, Ontario, and contains 42 to 45 per cent $FeCl_3$. Some trouble was experienced at York Township with the heavier solution during cold weather. It was found that considerable crystallization occurred in the tank cars. This has been overcome, however, by confining the strength to between 40 and 42 per cent in the cold winter months.

CENTRIFUGALS

By Jos. S. Pecker

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History

The application of centrifugal force for dewatering sludge is not new. It is a process utilized and found indispensable in many industries. Centrifugal machines are widely used on coal sludge, chemicals, sugar, oil and other industrial products. It is, therefore, obvious why sanitary engineers have anticipated the introduction into the sanitary

field of a successful centrifugal machine to dewater sewage sludge. Attempts to do this date back as far as 1900. Experiments in the last few decades proved partially successful, but for various reasons were abandoned.

The problems associated with the dewatering of sewage sludge are rather complex:

1. Sewage sludge combines a multiple of solids with varying specific gravities.
2. The physical characteristics of the liquids in which these solids are suspended varies considerably.
3. The solids held in suspension, including colloidal solids in sewage, require centrifugal intensities many times the force of gravity.
4. Large volume production is absolutely essential to make the centrifugal process economically practical.

The machine now installed at the North Toronto Sewage Treatment Works, to be discussed in this paper, is the evolutionary product covering years of careful research, design and experiment.

In 1933 a new series of experiments were initiated and a comprehensive research program was undertaken for the purpose of correlating all of the data previously obtained.

The research program covered experiments on centrifuges ranging from 12 in. to 40 in. in diameter. Many sanitary engineers, conversant with previous endeavours in the use of centrifugal machines, were consulted for their constructive suggestions. On the completion of this study a design was prepared involving principles of operation that were clearly a demarcation from any of those employed in the past.

A full-sized, practical, commercial machine was built and installed at the Collingswood Sewage Disposal Plant in New Jersey in 1934. Its subsequent operation constituted full justification of our research work.

Then followed a period in which we studied the operation of the machine, and the technique required for efficient operation. Eventually this study resulted in a new design of machine and auxiliary equipment, forming a unit plant. A machine based on this new design and manufactured by Canadian Allis Chalmers Company is now in operation at the North Toronto Sewage Treatment Works.

Description of Machine

Our centrifugal machine weighs approximately 20,000 lbs. The basket or bowl is 42 in. in diameter. The maximum purging or separating speed is 2,000 r.p.m. At this speed there is developed a separating intensity of more than 2,500 times gravity. With this intensity the cake is compressed under an average pressure of 600 lbs. per sq. in. The bowl or basket is divided into several compartments. The wall between them consists of a special honeycombed plate in which the retarding influence of the viscosity of the liquid is diminished, thus increasing the separating effect to 25 times that obtained in the chambers, thereby enabling us to separate both coarse and fine solids.

The centrifugal machine may be termed a restrained type of centrifuge in that the basket shaft, with bearings, is rigidly mounted against eccentric displacement.

The machine may be considered a continuous automatic centrifuge in that it continues operating from the time it is started and will cease operating only at the discretion of the operator. It may be termed a continuous batch machine in that the production is based on automatically repetitive cycles.

The complete cycle of operation is controlled through an electric panel constructed to our specifications by Canadian General Electric Co. The cycle of operation is as follows:

The machine is started by an electric push button. On starting it goes through a cleaning operation as a precautionary step to insure that the basket may be free of material, thus obviating any possibility of admitting sludge to a partially filled basket; as it is possible that the machine had been stopped prior to the completion of its previous cleaning operation. At the end of the cleaning cycle the high speed motor is energized and accelerates the basket to its maximum speed.

During the period of acceleration a bucket elevator sludge feed is started automatically and continues feeding for a length of time determined by the setting of a Telechron Clock on the control panel. At the expiration of the pre-determined time, the feed is automatically shut off and the basket is decelerated to a slower speed. Simultaneously another motor is energized to start the cutters operating.

There are two cutters, pivotally mounted, diametrically opposite to each other. Normally these are in a closed position concentrically arranged adjacent to the shaft. When put in operation these cutters open outwardly into the path of the cake, cutting, shredding and converging the material towards the centre of the basket and discharging the shredded sludge cake vertically through openings in the bottom of the basket and on to a conveyor belt located in the pit directly beneath the machine.

When the cutters have opened to their full limits, and the shredding operation is completed, they are automatically reversed, returning to their normal static position. At this point the slow speed motor, that has been driving the basket during the cleaning cycle, is de-energized, the high speed motor re-energized and the cycle is repeated.

In the feeding of sludge to the machine, we utilize a bucket elevator which lifts the sludge several feet above the machine and delivers the material to a hopper. A pipe connecting with this hopper conveys the material to the machine and vertically through the machine to the bottom of the basket.

This bucket elevator is driven by a variable speed drive which may be quickly adjusted to obtain the desired gallons per minute feed.

A Telechron Clock on the control panel may be adjusted from 1 to 30 minutes, the setting determining the length of time that the bucket elevator feeds material to the machine. By this means the operator has, at his disposal, a thoroughly flexible control for the determination

of the gallons per minute he desires to feed to the machine, and the total number of gallons per cycle.

As the characteristics of the incoming sludge vary in per cent solids, necessitating varying the gallonage per cycle, the advantage of this flexibility becomes immediately obvious. Both the change in feed in gallons per minute and the gallonage per cycle may be adjusted in a few seconds at any time while the machine is either running or stationary. The complete automatic operating cycle readjusts itself whenever the operator varies the setting of the Telechron Clock.

Sludge may be delivered to the machine directly from the preliminary tanks or from storage or thickener tanks without intermediate processes involving chemical conditioning.

Any quantity of greases entering the plant would neither clog nor retard separation. No special provision need be made in the primary settling tanks for the removal of greases, inasmuch as, with our machine, these greases are removed with the effluent and through the medium of a simple grease separating tank which we have developed, the greases may be skimmed off, incinerated with the cake and thus prevented from returning to the plant or passing out with the effluent.

In our two and one-half years of practical operation of the machine at Collingswood, N. J., we have endeavoured to work out a process for the most efficient utilization of the machine. Several controlling factors were observed, namely:

1. That chemicals were no aid in dewatering by centrifuge. Chemicals were tried without any appreciable advantages noted.

2. Although best results are obtained with fresh sludge, a reasonable variation of the pH of the sludge is relatively unimportant.

3. The increased production of the machine, increased per cent separation and the reduced moisture in the cake will vary almost directly with the decrease of moisture content in the sludge being dewatered.

4. With decreased moisture content of sludge, hours of machine operation are decreased.

It is, therefore, deemed advisable to introduce a relatively small thickener tank between the settling or primary tank and the dewatering equipment. These thickener tanks would also serve as storage tanks. The effluent from our machine would be returned to the thickener.

In dewatering raw, undigested, reasonably fresh sludge ranging from 93 to 95 per cent moisture content, we obtain an average separation of 90 per cent, with a moisture content in the cake averaging 62 per cent. On a combination of undigested, activated and primary sludge where the activated solids are about 50 per cent of the total, we obtain a 75 per cent separation or better, with the moisture content in the cake ranging between 65 and 70 per cent.

In the dewatering of screenings or a combination of screenings and coal (the installation being made at Niagara Falls, N. Y.), the moisture content of the cake will be below 50 per cent and the separation well over 95 per cent.

The above conclusions are the result of innumerable tests conducted at the Collingswood plant in New Jersey. We have as yet not had the opportunity of confirming these results in our operation at the North Toronto plant. Our centrifugal machine has been in operation only a very short time and this time has been devoted almost exclusively to testing out the machine and its accessory equipment. We plan to use another week or two to determine the best technique or process in operating the machine on the particular sludge developed at this plant after which time the machine will be put on full-time plant operation.

Incineration of Sludge

The question of incineration is a broad one, and while no attempt will be made in this paper, to discuss it in detail, reference to it would appear opportune.

It is of more than passing interest to state that the sludge from our centrifugal machine, both at Collingswood and in the last few weeks at Toronto, has been readily incinerated in standard garbage incinerators.

The problem of incineration is primarily concerned with evaporation of the water in the cake. It is, therefore, obvious that by reducing the moisture content in the cake we reduce the volume of water to be evaporated. Furthermore, the efficiency of incineration is dependent upon the combustibles in the cake in relation to its moisture content. By eliminating chemicals and other inert material, we improve the ratio between the volatile and the ash content in the cake. Furthermore, by shredding the cake we contribute to efficient evaporation and subsequent combustion.

Installation and Servicing of Machine

The installation of a single machine and its auxiliary equipment requires a maximum of 400 sq. ft. A battery of machines may be installed in a small, simple, inexpensive building. One operator can readily handle a battery of machines, as the duties do not involve any special labor except of a general supervisory character.

The machine is so designed that it may be operated without the need of technically skilled labor. All important parts are so assembled as to facilitate quick removal and re-assembly, without any possibility of misalignment.

By removal of a dozen bolts, the entire top portion of the machine may be removed as a complete unit. On this top plate are mounted the cutters, the operating mechanism for the cutters and the influent pipes. With this unit removed from the machine, as an integral assembly, the whole basket assembly comprising the basket, shaft and roller bearings, on which the basket is mounted, may be removed as a second unit.

The entire machine is constructed of alloy materials all carefully heat treated. Those parts subjected to high stresses are carefully calculated to dimensions ensuring high factors of safety.

Summary

Based on the foregoing, the following advantages may reasonably be claimed for the centrifugal dewatering of sewage sludge:

1. Centrifugal dewatering may follow immediately after primary settling or chemical precipitation.

2. Chemical conditioning, prior to dewatering, is not required, thereby effecting economies in chemicals, chemical feeders, conditioning tanks, piping and pumps and labor attendant on these various factors.

3. Where incineration is adopted as the means of ultimate disposal, the centrifugal cake, with low moisture content and free from inert material, shredded to facilitate evaporation, should require less fuel and produce less ash than other types of sludge.

4. Chemical control of pH to compensate for the change in characteristics of the sludge is not required; consequently highly technical operation is unnecessary.

5. The whole equipment may be housed in compact, inexpensive buildings, requiring only a minimum of land area.

The introduction of the centrifugal process for dewatering sewage sludges is definitely in line with the trend in mechanizing the disposal plant. It marks a constructive and progressive departure from established practise.

SEWAGE DISPOSAL IN MICHIGAN *

By E. D. Rich

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The State of Michigan was set off from the Northwest Territory in 1836 and we are this year celebrating our century of statehood. The land area of Michigan is 57,980 square miles, only a little more than one-sixth of that of the Province of Ontario. However, the population is 41 per cent greater. The figures show a population density of 8.4 persons per square mile in Ontario as against 83.6—nearly ten times as much for Michigan. Since the sparsely settled country to the north is greater in Ontario than in Michigan, it is probable that the density of population in those parts of both Michigan and Ontario in which most of the sanitary problems arise is not greatly different. The drive from Detroit to Toronto or Niagara Falls reveals a country very similar to Michigan. Like Ontario, Michigan has three cities above 100,000 in population.

Detroit	1,568,662	Toronto	570,000
Grand Rapids	168,592	Ottawa	118,000
Flint	156,492	Hamilton	125,000

The soil is extensively composed of deep sand and gravel deposits left by the receding glaciers during the various ice ages. Such a soil is absorptive and affords a ready means of sewage disposal for small quantities of sewage and thus keeps some out of the streams. Natural storage of water in sandy soil regulates the flow of streams and prevents great contrasts between flood flow and dry weather flow. During 1936 dry stream beds have appeared in Michigan. Another advantage realized from gravel formations is the abundant ground-water resources easily utilized by municipalities, making it somewhat less necessary to protect streams against pollution for the sake of public water supplies. Many municipalities, even with populations as large as 90,000 obtain water from wells and thus avoid the cost and difficulties of filtration of the public water supply.

In many cases cities have developed at the points where important rivers empty into the Great Lakes. These streams are polluted, to some extent at least, by the municipalities along their courses, but more specifically by the sewage of the cities at their mouths. For this reason sewage treatment plants are built at these places for the protection of the public water supplies taken from the lakes and also for the protection of the bathing beaches along the lake shore, and for the elimination of nuisances arising from objectionable odors and unsightly conditions due to the discharge of sewage into the lake or stream.

In 1911 there were nine municipal and six institutional sewage treat-

* Presented before the Canadian Institute on Sewage and Sanitation, Toronto, Ontario, Oct. 1, 1936.

ment plants in service in this state. These served about 66,000 people. Of these, three municipal plants and one institutional plant remain in service unchanged; one municipal plant has had some repairs but is in use practically as originally built; and four municipal and four institutional plants have been replaced with works of modern design and efficiency. One municipal plant was abandoned a number of years ago and is now being replaced by a modern plant which will be ready for operation within a relatively few weeks. One institutional plant was replaced by a more modern plant but is now closed and the sewage is connected to a nearby municipal system. Three other plants were discontinued when the sewers were connected to a city system. It is interesting to note that the first report of the Bureau of Engineering of the Michigan Department of Health, made in 1914, a year after the Bureau was established, states that 12 municipalities were contemplating new plants or major extensions of old ones. Of these, seven have plants built or in service for some time. Two have received bids for new plants; one started work in 1936; and the other two have done nothing but have engineering studies made. By 1915 the list of municipalities served had increased to 28 and 15 communities were listed as considering construction of Imhoff tanks. In September, 1936, there are 66 municipalities and 22 institutions having plants now operating. In addition there are seven other municipalities having small plants in service or partly serving the community and 9 having new plants in various stages of construction. This makes a total of 104 plants now in operation or under construction in Michigan. These plants serve municipalities with a population of 848,660.

Work has been started on the preparation of plans for sewage treatment for the city of Detroit and several contracts have been let for the building of the main collecting sewer, or interceptor, from its present terminus to the treatment plant site, a distance of about five and one-half miles. Contracts have been advertised for some of the equipment but the plans for the structures have not yet been submitted to the Department of Health for approval. It is expected that these drawings will be ready for our inspection within a relatively short time. When the Detroit plant is finished the population served by sewage treatment plants will be increased by more than 1,500,000. Doubtless this work will have a more direct effect upon the Dominion of Canada than will any other work of this nature which has been or will be undertaken by the State of Michigan.

I fear that the Treaty of 1909 between the United States and Great Britain has been violated by the discharge of pollution into the Detroit River, chiefly from the city of Detroit and its environs, but I, personally, appreciate very fully the tolerance and patience which has been exhibited by the Dominion of Canada and the Province of Ontario in omitting to file a formal complaint with the United States Government. Certainly our conscience will be much clearer after the Detroit plant is completed and then we will not be in the position of causing an embarrassment or danger to our neighbors across the river.

Methods of sewage treatment change from time to time as new developments are brought out, much as automobiles and other mechanical devices change as new innovations and inventions are perfected. Prior to 1912, substantially all of the plants in Michigan were so-called "septic tanks." This was followed by the development of the Imhoff tank and its general adoption from the period beginning about 1910 and extending to about 1925. This, in turn, has been largely superseded, beginning about 1925, by the development of mechanical sludge removal equipment, and similar other mechanical devices for use in sewage treatment. Apparently we are now beginning a new stage in the science of sewage treatment through chemical precipitation, which had some use early in the century, but without much success largely by reason of the lack of suitable methods of sludge removal and disposal.

At various times during these years certain secondary processes such as activated sludge, trickling and sand filters, were also developed to a stage of considerable importance and were quite generally used. A review of the past would indicate that in too many cases the tendency has been to adopt the device currently popular and discard the proven devices of previous years more for the reason that the new device is new rather than that the old one was defective. It would seem that progress would best be made by a careful consideration of the demonstrated merits and defects of the older devices together with a judicious and open-minded examination of the newer developments.

The financing of sewage treatment plants is not, strictly speaking, a matter for consideration by the State Health Department. Plants may be paid for by any method open to the municipality and it is for them to choose what plan they may wish to adopt. Practically, however, it is a matter of great concern to the Department, for financial difficulty is a major obstacle in the securing of new plants and in the maintenance of existing ones. It is manifestly a matter of great importance to the operator for without adequate financial resources he cannot possibly operate his plant in a satisfactory manner.

Formerly the matter of financial resources was not of so great importance as it now is. Or perhaps we should more correctly say it was not permitted to be of so great importance. The plants were simple and the operation simpler, consisting chiefly of doing nothing. Obviously this did not require any great share of the municipal budget—at least until the time came for paying damage suits or reconstructing plants, which, of course, was a "bridge not to be crossed until reached." Unfortunately the idea that substantially no funds were necessary to operate a plant was promoted by, among others, some of our friends of the engineering profession, possibly through misinformation and more probably through a selfish interest, for, by using a minimum figure in estimated costs of maintenance, municipalities could be more easily induced to undertake the construction of a plant. Although minimized to some extent, this tendency is still in existence in Michigan and is one of the reasons for encouraging engineers to attend operators' meetings.

Many municipal charters make no specific provision for financing

sewage treatment works, either as to construction or operation. As a result it has been the usual practice until recently to meet the cost of construction of sewage treatment plants by general bond issue, and to defray the principal and interest payments out of the general tax levy. Similarly the operation costs were also met by a portion of the general tax levy. More recently the utility idea has been extended to include the sewage treatment works. This has been done by an act of the Michigan Legislature passed in 1929 which authorized mortgage bonds which are secured by the plant, its revenues and its franchise. A subsequent act passed in 1933 provides for the issuance of bonds for the construction of sewage treatment works but the bonds are secured only by the revenue of the plant. This act has been very extensively used under the recent Public Works Administration financing and has been pronounced constitutional by the Supreme Court of the state of Michigan.

The theory underlying the use of the utility method of financing expressed simply is that the user should pay for service rendered. This is reasonably sound and probably as fair as any single method that can be adopted. However, it may fairly be pointed out that, particularly in the case of interceptors and trunk sewers, a material part of the cost of the system is provided for future growth and that any system of financing which requires the users at the beginning of the life of the project to carry the fixed charges on an investment larger than they need so that later users may be served, may be paying an unfair proportion of the cost. Perhaps this might be remedied by an arrangement providing for a certain part of the construction cost to be defrayed by general tax or special assessment and the operating cost and the rest of the construction cost paid by users.

Perhaps it may not be exactly just, but in communities where a high percentage of the general tax is paid by a single or a small number of taxpayers, there is a considerable hesitancy in adopting the so-called utility or sewer rental method of financing for the reason that it is much easier to have the smaller amount of cost assessed against the greater number of citizens of the community than to adjust the cost directly in proportion to use. The greatest advantage in the utility or sewer rental method of financing lies in separating the funds for plant operation from the general funds of the city or village. When the plant's funds must come from the general funds of the city or village, its budget is almost certain to be restricted to such a degree as to seriously impair the efficiency of the plant, for the sewage treatment plant is likely to have few staunch supporters in the legislative body when the budget is made up, and as a consequence, suffers in competition with other municipal activities. Furthermore with a specific source of income the operator can better plan his activities, and the results of economical planning and operating can be immediately shown to the man who pays the bills. In the same manner inefficiencies in operation, reflected in increasing or exorbitant rates, are likely to become evident and the day of retribution brought nearer.

The costs of operation of plants will of necessity vary from place to place, depending upon size of plant, type and degree of treatment necessary, material costs, prevailing wage rates, power costs and so on. The actual cost of sewage treatment should properly be divided into two parts, and the accounting system for the plant should be set up to show these divisions. First are the fixed charges. These consist of the interest on funds invested, a sinking fund allowance for bond retirement, and provision for depreciation on the structures. These items are as truly a part of the cost of sewage treatment as the operator's salary and in most cases are considerably greater in amount. As to just how much of the system should be included in determining this cost, it would seem that this would properly be dependent upon the organization of the city. If the sewer system and its apurtenances, including lifting stations, trunk, lateral and intercepting sewers and treatment works, are all to be financed as one department or function, then the whole system might properly be included but separated, if so desired, into the divisions of collection and treatment. Where pumping is necessary only for the reason that sewage must be treated, then it would appear that pumping is a logical cost of sewage treatment, but where it is necessary perhaps only to provide adequate collection service for a low district, then it is clearly only a collection function and not a part of treatment and should be so charged.

The second part of the cost of sewage treatment is operating costs. These should include those items of expense actually incurred in operation—salaries, power, supplies, chemicals, telephone, water, etc. These may be subdivided as desired, although most plants are not large enough to warrant any greatly detailed subdividing.

The Michigan Department of Health is charged by law with the duty of examining plans for the construction of and supervising the operation of sewage treatment plants in our state. Until recently the Bureau of Engineering was limited in personnel to such a degree that adequate supervision and frequent contact with the operators had been of necessity somewhat neglected. Last spring the Federal Government provided for funds to be allocated to the various state health departments, through the United States Public Health Service, to assist them in extending their work. From this fund two additional engineers were engaged, one of whom spends practically all of his time in supervising the operation of sewage treatment plants and consulting with the operators to help them with their problems. In this way we hope to see that improvement is made in the operation of many of the plants which have not received the attention which they require.

It has always been the policy of the Michigan Department of Health to maintain a free and cooperative spirit between the operators and the representatives of the department. We prefer to picture each operator as a member of the department, with his particular task the operation of his plant, willing and ready to give his advice and assistance to us and to other plant operators when need arises.

A few remarks about some of the individual plants in Michigan may

be interesting. At Pontiac, with a population of 65,000, the trickling filters, built in 1921, were the first in the United States to be equipped with rotary distributors of the Adams type. The first major replacements were made last year when it became necessary to renew the distributor arms. These should have been replaced two or three years sooner.

The plant at Flint, a city of 156,000, consists of Imhoff tanks and trickling filters, but there are some unique features in the design. The tanks embody the principal of radial flow and are composed of sections, or cells, hexagonal in form grouped around a central hexagon through which the sewage enters. In each unit there are two rows of hexagons, 18 in number. The effluent is drawn off around the outside of the outer row, there being one outlet for each cell. There are four such units, and provision was made in the design for constructing four more to meet future requirements. This type of tank has proved rather unexpectedly efficient; so much so, indeed, that the sludge storage capacity has proved to be too small. Severe difficulties with foaming have occurred much of the time since they were built in 1927 This design has two advantages. First, the principle of radial flow, and second, the cost was less than for tanks of equal capacity built in accordance with conventional designs. This was partly because some of the tank parts were built of pre-cast slabs. The sewage, after passing through the tanks, receives about 20 minutes of aeration to saturate it with oxygen for the purpose of increasing the rate in the trickling filters. The aeration tanks are enclosed in a building and this operation, to some extent, aids in odor control. The final tanks are of the continuous sludge removal type and are rectangular in plan.

An activated sludge plant constructed in 1931 at Muskegon Heights, a city with a population of 10,000, was the first plant of that type of modern design in Michigan. It has been giving excellent service under the management of a very competent operator. It replaced a plant consisting of Dortmund tanks, sludge tank, contact filters and sand filters. Some parts of the old plant are still used.

The City of Jackson, with a population of 55,000, has practically completed a modern activated sludge plant to eliminate the gross pollution of the Grand River in its upper reaches, which has been evident for as much as thirty miles below the city. The flow of the river has been known to go as low as ten cubic feet per second.

An activated sludge plant was built soon after that process was suggested at Escanaba which has a population of 15,000, but was not very efficient and the operating costs were high. It was replaced in 1934 by an activated sludge plant of modern design. A trickling filter is also a feature of this plant. Sedimentation is by means of rectangular tanks with continuous removal of sludge and digestion in a separate tank. This plant is modern in every way and is giving satisfactory service.

Grand Rapids, having a population of 169,000, constructed a plant in 1931 consisting of clarifiers of the Dorr type and separate sludge

digestion. The operator was successful in the sale of fertilizer manufactured from the sludge. Activated sludge as a secondary treatment was included in the design but a shortage of money postponed the secondary process. As the Grand River below Grand Rapids is loaded with pollution to the limit by the effluent of this plant, it will shortly be necessary for the state to take action to insure the completion of the plant as originally designed. It is probable that chlorination will also be included for the protection of recreational uses of the stream.

The plant at Dearborn, a city having a population of 50,000, is of unique design. The sewage is treated with ferric chloride and then passes through circular clarifiers with radial flow. As the effluent passes out of the tank it must flow upward through a layer about four inches deep of magnetite sand supported on slotted brass plates. This coarse sand layer strains out the fine floating particles which otherwise would pass out in the effluent. An electrical device supported on the traction arm of the clarifier stirs the sand as the device passes over it and a pump takes away the dirty water which has served to clean the sand. This goes back to the tank inlet for resedimentation. The stream which receives the effluent from this plant is highly polluted but will be improved when the Detroit plant is finished. It is hoped that there will be dilution enough provided by this stream, the River Rouge, so that further treatment of the Dearborn sewage may not be necessary. Part of the sewage from the City of Dearborn is treated in an old plant about three miles away. This consists of Imhoff tanks. These are now used more as plain sedimentation tanks because the sludge is taken out frequently and pumped to the chemical precipitation plant where in combination with the sludge from the chemical process, it is dewatered on Oliver dryers and incinerated.

Operators' Reports and Suggestions

W. D. Hatfield

219 Linden Place, Decatur, Illinois

SUPPLEMENTARY SUGGESTIONS FOR THE OPERATION AND CONTROL OF SEWAGE TREATMENT PLANTS

NEW YORK STATE DEPARTMENT OF HEALTH, ALBANY

By C. A. Holmquist

Director, Division of Sanitation

The form reproduced here is suggested as an excellent model for recording of operating data. It accompanies the instructions issued to sewage works operators in New York State in 1930, and published in this Journal, 2, 597 (October, 1930). Interested readers can undoubtedly obtain a copy of this form by writing to Mr. Holmquist.
Form San. 46.

To New York State Department of Health:

Date. Time (1). Weather (2). Wind Direction (3). Temperature: Air (4); Sewage (5). Sewage Flow Rate Gallons per day (6). Screenings Cu. Ft. (7). Settling Tanks: Skimmed (8); Imhoff Tanks—Slots Cleaned (9); Scum Broken (10); Flow Reversed (11). Separate Digestion Tanks: Sludge Added Cu. Ft. (12); Gas Produced Cu. Ft. (13). Sludge Condition: Sludge Depth (14); Scum Depth (15); pH (16); Temp. (17). Sludge Removed: From Tanks Cu. Ft. (18); Color (19); Odor (20); From Beds Cu. Ft. (21); Drying Time (Days) (22). Dosing Tanks: Counter Readings (23); Filling Time (Min.) (24); Cleaned (25). Trickling Filters: Nozzles Cleaned (26); Lines Flushed (27); Condition of Bed (28). Sand Filter Beds: In Use (29); Resting (30); Being Cleaned (31). Final Settling Tanks: Sludge Depth (32); Sludge Removed—From Tank Cu. Ft. (33); From Bed Cu. Ft. (34). Chlorination: Weight of Tanks (35); Pounds Chlorine Used (36); Weight New Tanks (37); Rate—Day (38); Night (39); Residual Chlorine (P.P.M.)—Time (40); Initial Test (41); Second Test (42). Settleable Solids (c.c. per liter—1 hr.): Raw Sewage (43); Tank Effluent (44); Filter Effluent (45); Final Effluent (46). Putrescibility: Filter Effluent (47); Final Effluent (48). Date. Treatment Costs (49): Labor, Power, Chemicals, Misc., Total. Conditions in vicinity of or below outlet (50). How sewage flow is determined (51). How sludge is disposed of (52). Operating problems or assistance desired (53). Industrial waste problems (54). General Notes (55). Analytical Data (56): Sludge Analyses—Date; Fresh Solids: Per cent Solids; Vol. Cont.; Digested Sludge: Per cent Solids; Vol. Cont.; Dried Sludge: Per cent Solids; Vol. Cont. Biochemical Oxygen Demand (P.P.M.): Date; Raw Sewage; Tank Effluent; Filter Effluent; Final Effluent; Stream Above; Stream Below. Suspended Solids (P.P.M.): Date; Raw Sewage; Tank Effluent; Filter Effluent; Final Effluent—(Daily Det'ns). Presumptive B. Coli (gas formation): Samples—Final Effluent: Dil.; 24 Hr.; 48 Hr. Date. Dissolved Oxygen (P.P.M.): Date; Filter Effluent; Final Effluent. Nitrates (P.P.M.): Filter Effluent; Final Effluent.

Explanation of Report on Operation of Sewage Treatment Plants

This report form is to be used for keeping a daily record of the operation of sewage treatment plants in New York State, and should be submitted monthly to the State Department of Health. Following is an explanation of the information which should be recorded. The items are numbered to correspond with the numbers appearing in each column.

1. The time at which observations are made.
2. Weather conditions (abbreviated), e.g., F = Fair, C = Cloudy, R = Rain, S = Snow.
3. Direction from which wind is blowing.
4. Air temperature (F°) at observation time. If maximum and minimum thermometers are used, record both temperatures.
5. Raw sewage temperature (F°).
6. Rate of sewage flow at observation time. If recording meter or other recording devices are used, record the total daily flow.
7. Number of cubic feet of screenings removed daily.

8. Indicate by cross (x) on days when floating solids are removed from settling tanks.
9. Make cross (x) on days when slopes of settling compartments are squeegeed and slots cleaned.
10. Make cross (x) on days when scum in gas vents is broken up.
11. Make cross (x) on days when direction of flow is reversed.
12. Number of cubic feet of sludge added to the digestion tank. If measurement impracticable make cross (x).
13. Number of cubic feet of gas produced daily (if metered).
14. Depth of sludge in tanks measured once a month or oftener.
15. Depth of scum layer in tanks measured once a month or oftener.
16. The pH value of the digesting sludge once a month or oftener.
17. Temperature (F°) of the digesting sludge at least monthly.
18. Number of cubic feet of wet sludge removed from digestion tanks.
19. Color of sludge removed.
20. Odor of sludge removed.
21. Number of cubic feet of dried sludge removed from drying beds.
22. Number of days required to dry sludge to a condition suitable for removal.
23. Readings of the dosing tank counters each day or preferably the total number of dosing tank discharges each day.
24. Time (minutes) required to fill dosing tank at observation time.
25. Make cross (x) on days when dosing tank is cleaned.
26. Number of nozzles cleaned each day.
27. Make cross (x) on days that distribution lines are flushed.
28. Record condition of bed weekly, describing surface growth, by development, unloading, pooling, etc.
29. Indicate by numbers or letters the beds in use each day, e.g., 2, 3, 6 or B, C, E, etc.
30. Beds draining, drying or "resting" as above.
31. Beds being raked and cleaned as above.
32. Depth of sludge in final settling tanks weekly.
33. Cu. ft. of wet sludge removed from final settling tank.
34. Cu. ft. of dry sludge removed from sludge bed.
35. Total weight of the chlorine cylinders in use, weighed at the same hour each day.
36. Actual weight of chlorine used during preceding 24 hours.
37. Total weight of new cylinders when connected.
38. Day rate of application of chlorine in pounds per 24 hours as indicated by manometer or scale reading on chlorinator.
39. Chlorinator rate during night hours as above.
40. Residual chlorine test to be made at time of maximum flow or concentration of sewage (usually between 9 A.M. and 12 M.).
41. Result of residual chlorine test at time noted under 40.
42. Result of second residual chlorine test where two tests are made daily or where first test shows adjustment of chlorination rate is necessary.
43. Settleable solids in raw sewage (c.c. or ml. per liter—1 hour settling) determined by Imhoff cone test daily.
44. Settleable solids in primary tank effluent as above.
45. Settleable solids in effluent from filter bed.
46. Settleable solids in final effluent.
47. Number of days for decolorization of methylene blue in sample of filter bed effluent at least once a week.
48. Putrescibility of final effluent as in 46 above.
49. Monthly cost of operating treatment plant.
50. Brief description of prevailing conditions in stream or body of water in vicinity of or below plant outlet.
51. Method of determining sewage flow.
52. State how sludge from the plant is finally disposed of.
53. Describe briefly any operating problems which arise, your solution of problem, and state if assistance from the Department is desired.
54. Keep record of industrial wastes, such as oil, tar, chemicals, dyes, milk wastes, canning wastes, etc., noticed at plant.
55. Make notes regarding any operating conditions not specifically mentioned above.
56. Keep record of results of all analytical determinations carried out in plant laboratory.

These reports should present a representative picture of operating conditions at the plant so that this Department may be informed and be able to advise and assist the operator in correcting difficulties and maintaining the maximum efficiency of the treatment plant at all times.

PENNSYLVANIA SEWAGE WORKS ASSOCIATION SEWAGE WORKS CLINIC *

Operating Fundamentals

By Lewis V. Carpenter

Associate Professor of Sanitary Engineering, New York University.

What should an operator know about his plant?

a. An operator should get a complete set of plans of the plant and study them so that he knows every valve and other detail on them.

b. He should know "why" you do everything you do about a plant. If it is collecting samples, skimming scum, or what-not, he should be able to tell occasional visitors why that operation was performed.

Why should an operator keep records?

Records are necessary: (*a*) To indicate whether the plant is functioning properly. (*b*) In case law suits arise from operation of the sewage plant. (*c*) To provide suitable data for the design of extensions to the plant. (*d*) To provide data for an annual report. (*e*) To allow the operator to take stock of just what he has accomplished.

Every operator should issue an annual report, which should be distributed to newspapers, business men, and municipal officials. One operator of a small plant bought a small pan duplicator, three different colors of ink, and some paper. He put out a 20-page report of the operation of the sewage plant and all of the supplies necessary for this report cost less than $5.00.

Should an operator keep a daily log?

Municipal officials are always ready to criticize employees; it is well to have some form of record to show just what we do with our time. It is highly advisable for a sewage plant operator to get a regular log book (not loose leaf) and enter in it every operation he performs with the time it took to perform the task. When keeping a daily log we are taking inventory of ourselves, and if we sit and dream, enter it as such.

Should a sewage treatment plant be kept clean?

The sewage plant is the operator's day home and the same cleanliness should be set as would be set in his own home. These remarks apply not only to the laboratory but to the screen chamber, the Imhoff tank, etc., and certainly to the grounds outside. After you have set your plant in order, then begin bragging about it. Go to the nearby schools and invite the teachers to bring the children over. Explain the plant in simple language and they will go home and tell father and mother about it. Small children are the best advertisers, women next, and last civic clubs.

For a nominal cost, signs can be painted and placed near each separate unit at the plant. Explain as much as you can. After the signs have been painted, give them a coat of clear shellac about every three months so as to keep them shiny. A sign that impressed me very much said, "Taxpayers, this is your plant, come on in and see how it operates." This was erected in front of a well kept sewage plant. That is much better than the standard "Visitors Welcome" sign.

An operator to be successful must be a publicity man. First, get your plant so that you are proud of it. Then tell everybody to come and see their plant. They will soon be proud of it too.

* Presented before the Tenth Annual Conference of the Pennsylvania Sewage Works Association, State College, June 25, 1936.

Activated Sludge Plant Operation

By A. J. Fischer

Sanitary Development Engineer, The Dorr Company, Inc., New York

1. *What is the best procedure to follow in starting up an activated sludge plant?*

Continuous plant operation in a normal manner will build up activated sludge in from two to four weeks. During this period larger air volumes should be used.

2. *What causes "foam" on aeration tanks?*

Foam on aeration tanks during starting-up periods is indicative of a lack of sufficient activated sludge to satisfactorily take care of the incoming fresh sewage load.

3. *What simple tests can an operator perform to determine if his aeration plant is operating satisfactorily?*

(*a*) Settling tests of the mixed liquor at the inlet and outlet end of the aerators; (*b*) Suspended solids tests on aerator mixed liquor, return activated sludge, and final plant effluent; (*c*) Dissolved oxygen tests on settled mixed liquor; (*d*) B.O.D.'s and relative stability tests on final effluent; and (*e*) Sludge blanket depth determinations in final clarifiers.

4. *What should be the solids content maintained in the aerator mixed liquor?*

In general, it is desirable to carry about 1500 to 2000 p.p.m. solids in the mixed liquor of air diffusion plants. In the case of mechanical aerators, 1000 p.p.m. appears to give better results.

5. *In an air diffusion plant how should the air quantity required be determined and regulated?*

Immediate oxygen demands may be determined at various parts of the tank and the air volume regulated so as to maintain some excess dissolved oxygen in all parts of the tank. More air is required at the inlet end of the aerator. This is tapered off to a minimum at the outlet end.

6. *How can the air requirements be determined and regulated in a mechanical aeration plant?*

This is done by varying the speed and/or submergence of the aerator units.

7. *What is a "bulked" sludge and what are some of the most common causes of "bulking"?*

A "bulked" sludge is one having a high "sludge index" value. The most common causes of "bulking" are underaeration, presence of trade wastes, especially of a high carbohydrate content, and presence of filamentous organisms.

8. *What is the "sludge index" value?*

The "sludge index" is the volume in c.c. of 1.0 gram of sludge solids.

9. *What are some of the methods of curing "bulking"?*

In the case of underaeration, adding a greater volume of air, temporarily by-passing the aerator, or reducing the solids in the mixed liquor, will help. Where filamentous growths are present as evidenced by microscopic determination, the addition of lime or a rich grade of garden soil high in nitrifying bacteria, is beneficial.

10. *What is the best method of "wasting" sludge?*

In small plants, by adding a small volume of sludge continuously to the inlet of the primary clarifier. In large plants, by adding the excess sludge to a separate thickener or decanting tank.

11. *What is the most economical and satisfactory way of disposing of waste activated sludge?*

In the smaller plants (15 m.g.d. or less), by digestion. In the larger plants (over 15 m.g.d.), by direct filtration and incineration. Unless recovery of gas from digesters for power degeneration are important considerations.

12. *What plant records should be kept, and how may they be used in assisting future operation?*

The following records should be kept: (1) Sewage flow—max., min., aver.; (2) return sludge volume; (3) final clarifier sludge depth; (4) settling tests—mixed liquor; (5) suspended solids—(*a*) mixed liquor, (*b*) return sludge, and (*c*) raw sewage, settled, and final effluent; (6) dissolved oxygen in settled mixed liquor; (7) B.O.D.'s on raw sewage, settled, and final effluent; and (8) occasional ammonia, and nitrate tests on final effluent.

All chemical tests should preferably be run on daily composite samples collected at one or two hour intervals over the 24 hours.

These records will assist in predicting difficulties, for example, a rising "sludge index" and lowered dissolved oxygen will warn of bulking sludge and may indicate that more sludge must be wasted and a greater air volume added.

13. *What suspended solids content and B.O.D. do you expect to find in a good plant effluent?*

The B.O.D. should not exceed 15 p.p.m. and the suspended solids should be less than 20 p.p.m.

Imhoff-Trickling Filter Plant Operation

By R. R. Cleland

Sanitary Engineer, The Pennsylvania State College

The questions listed herein are for the purpose of promoting some discussion on several phases of plant operation rather than listing the routine that is required in a plant of this type. The answers to these questions pertain to the State College Treatment plant. It is hoped that this will end the discussion of our serious difficulties of operation since the Borough of State College is at present undertaking the construction of a plant of its own which, when built, will relieve our overloaded condition.

1. *How are screenings disposed of?*

Screenings, which amount to 0.83 cu. ft. p.m.g. are disposed of by using them for fill. They are covered with sludge from the drying beds and no nuisance results.

2. *Do you have any trouble with oil received from the sewer system?*

We have lately been receiving large quantities of oil in the College sewage and our efforts so far to trace it to the source have been unsuccessful. The oil remains on the surface of the flowing-through chamber where it has to be removed by skimming. To facilitate this procedure we use *sawdust or fine wood shavings* as the absorbing medium.

3. *Has the oil been noticeably affecting sludge digestion?*

It has. The Imhoff tank which receives the College sewage recently "went dead," so to speak. Digestion stopped to the point where it was impossible to notice any evidence of gassing in the vents and the sludge when drawn was void of gas, making drainage difficult. There was also a noticeable odor similar to kerosene in the sludge. We tried to remedy the condition by reseeding the tank with Borough sludge, by pH adjustment, and by sludge circulation. None of these methods produced results. We next elutriated the sludge by pumping raw sewage into it through the withdrawal pipe. For several hours we washed out a foul smelling, black liquor. Following this procedure the tank returned to normalcy. Anaerobic counts made on the sludge at the time showed 34,000,000/c.c. for the inactive tank while the Borough tank (working well) had only 5,000,000/c.c. This indicated that the sludge was not promoting sterility as a result of the oil, but was, in fact, promoting bacterial growth. No attempt was made to identify the organisms. It can be concluded that they were detrimental to sludge digestion since their elimination produced activity with a lower count of 4,000,000/c.c.

4. *How is foaming controlled?*

Our best remedy has been to draw sludge. Unfortunately, this is not always possible and when not we attempt control by beating out the entrained gas. Using a centri-

fugal pump driven by a gasoline engine, we can circulate the sludge and lessen the activity of the tank. Foaming is not a serious problem with us although it occurs frequently in a mild form.

5. *How do you control scum formation in the gas vents?*

When weather permits the gas vents are hosed and limed weekly. If several weeks pass and this is not done the scum will accumulate to a depth of 10 feet. If the washing of the vents is done just prior to or during sludge removal much of the material is drawn onto the beds. Whenever possible we remove the top matting with forks and haul it to our dump. Since it is composed mostly of cellulosic materials which would require long digestion periods, removal is the best solution. The scum in the partially digested stage creates no nuisance in disposal.

6. *Have you much trouble with psychoda and how do you combat them?*

Psychoda breed in the trickling filter and at times are over-abundant. Since the sprays on our bed fail to meet by approximately 18″ an excellent breeding place exists. This space was created by our own hand in that we had to increase the nozzle size to eliminate continuous siphon tank operation. By reaming the nozzles from 7/8 in. to 1 in. we abolished one evil but created another since it decreased the size of spray.

When the flies are reproducing rapidly we attempt control by adding orthodichlorobenzene to the siphon dosing tank and by valve manipulation increase the head on the filter to a height which causes the spray to overlap. By adding 1 gallon (approx. 300 p.p.m.) on successive days some results are obtained. Michigan State College has found that applications of 10 p.p.m. of this chemical, when added to the influent of a sewage filter, will effectively control the fly.

The time required for each application was, in their case, 7 days. In our case it is necessary to make the applications at intervals rather than continuously. When 300 p.p.m. were added we could not detect any trace of the chemical in the effluent. This is perhaps explained by the fact that the bed has an average depth of 8½ feet and is highly efficient.

7. *What attention do you give the trickling filter?*

The underdrains and laterals are flushed semi-annually. The undersides of the Taylor square spray nozzles are scrubbed monthly to keep the spray limit at a maximum. Pooling, when it occurs, is remedied by disturbing the stones with a bar or by closing a portion of the bed from service to allow air drying. Recently we cleaned the interiors of the mains, laterals, and risers by pulling through them stiff wire brushes. After 18 years of operation there had accumulated a black, greasy lining with a tarry odor. It had accumulated to a thickness of 3/8 of an inch.

8. *What is the rate of application of chlorine?*

Chlorine was fed to the effluent from the trickling filter at a rate of 3.97 p.p.m. during the past year, giving an average residual of 0.4 p.p.m.

9. *What is the efficiency of the secondary sedimentation tanks?*

From the standpoint of bacterial removal they give adequate detention period for sterilization. The effluent from the plant has a total bacteria count of 600/c.c. of which 0.7/c.c. are of the colon group. This represents a reduction of 99.9 per cent of the bacteria in the raw sewage.

Suspended matter in the effluent is high which is explained by the fact that there exist no facilities for continuous sludge removal, the basins having been constructed prior to that improvement. With the Imhoff tanks in an overloaded condition, the secondary sludge cannot be returned but instead has to be mixed with Imhoff sludge and dried on the beds. This means that the basins will be cleaned once or twice per month. The result is that some of the solids pass directly through the basin because of inadequate sludge storage space. Average figures for the solid content of the effluent are as follows:

Total	405 p.p.m.
Suspended	62 "
Settleable	56 "

10. *What has been your experience with open and covered sludge beds?*

During the past two years we have had an opportunity to compare open and covered sludge beds and can summarize as follows:

(*a*) In 2 years we have filled and cleaned the open beds 33 times as compared with 40 for those under glass. This represents an efficiency of 25 per cent for the covered over the open instead of 100 per cent as is claimed by manufacturers of such structures. Average moisture content of the sludge as removed was 77.7 per cent for the open and 70.3 per cent for the covered.

(*b*) Sludge can be lifted in the winter in a frozen condition with a moisture content of 85 per cent. On many occasions the loss of filter media will be less under these conditions than would be the case in the summer with the sludge containing 50 per cent moisture.

(*c*) Construction analyses will show that additional beds can be built for the cost of the covers. The open sludge beds require little maintenance while that for the covers is high.

With these factors in mind, we would prefer double area to single area under glass.

11. *What material do you use on the sludge beds?*

We are using crushed anthracite—effective size, 0.22 mm., Uniformity coeff. 3.5. We use the coal because we can buy it cheaper than sand on a volume basis.

12. *How do you condition sludge for the beds?*

We have been using ferric chloride and alum separately at a rate of 1 to 4 lb./cu. yd. (1–4 lb./100 lbs. dry solids) and have been getting good results. Better coagulation is obtained if we add lime ahead of the coagulants in the same amounts.

13. *What plant tests do you make?*

Since bacteriological analyses are performed on our drinking water in the same laboratory it entails little additional work to run the sewage. Average counts during the past year are as follows:

	Total Count/c.c. Nutrient Agar 20° C. 48 hours	Acid Count/c.c. Lactose Agar 37° C. 24 hours
Raw Sewage	1,690,000	180,000
Imhoff Effluent	1,510,000	185,000
Trickling Filter Effluent	114,000	8,900
Final Effluent	600	0.7

In addition to the above, such routine tests as suspended solids, relative stability, sludge analyses, both when drawn and lifted, pH, acidity, and residual chlorine.

14. *What is the cost of treatment?*

Treating on the average 575,000 gallons daily, the cost of treatment has averaged $27.35 p.m.g. This figure includes repairs but does not include fixed charges.

Separate Sludge Digestion

By C. H. Young

District Engineer, Pennsylvania State Health Department

What factors are chiefly responsible for the growth of separate sludge digestion plants?

The widespread use of the separate sludge digestion type of sewage plant in this country in recent years, can be attributed to the research work on sludge digestion by Rudolphs, Fair and associates, and others; and to the development of satisfactory mechanical equipment for cleaning settling tanks.

How does the operation of settling tanks affect sludge digestion?

Fresh solids digest more rapidly than septic solids, hence solids should be removed from the settling tanks as promptly as possible. The practical procedure is to vary the

pumping frequency from once daily at the smaller plants, to hourly at the larger plants. Low pumping rates of from 20 to 75 g.p.m. using a plunger-type pump, or screw-type centrifugal, are advisable. A simple guide used to assist operators in determining when the raw sludge has thinned sufficiently to stop pumping, is the "sludge concentration test." This consists of securing several samples of the sludge when it appears to have thinned at the end of the pumping period, mixing these, and placing 100 or 200 c.c. of the sludge in a graduate and settling ten minutes. A 30 per cent to 50 per cent sludge separation indicates a solids content varying from about 0.7 per cent to 1.2 per cent. Pumping upon this basis will keep clean settling tanks and will give, in most cases, a raw sludge moisture content ranging from 93 per cent to 97 per cent.

What part does the temperature play in sludge digestion?

Temperature has a very marked effect on the digestion of sewage sludge. Heukelekian gives the time required to digest seeded mixtures of sludge at different temperatures (N. J. Sewage Works Association Proceedings—1930), as follows:

Temperature F.	50°	60°	70°	80°	90°	100°	130°
Days	200–300	75	45	32	38	45	10
Relative Time		2.3	1.4	1.0	1.2	1.4	.3

Does seeding of sludge have an effect on digestion?

Seeding, which is the mixing of additions of raw into larger volumes of ripe sludge, likewise materially affects the rapidity of digestion. Lack of seed causes bulking, bad supernatant and foaming. Rudolfs recommends for digestion at 70° Fahrenheit, daily additions of fresh sludge not to exceed 2 per cent on dry solids basis of the ripe sludge present. This is approximately a digestion period of 50 days, which can be reduced with careful control.

Is reaction a factor in digestion?

The volatile content of sewage sludge is composed principally of organic solids, fats, and greases. As these materials begin to decompose, organic acids and carbonic acid (CO_2) form, both of which have an acid reaction. Later, as decomposition proceeds, alkaline substances form. If the fresh sludge is introduced daily into a proper volume of ripe sludge, the acid compounds which form first are neutralized as they form, by the alkaline ripe sludge present. Under this condition of digestion, a neutral or slightly alkaline reaction, pH value 7.0 to 7.6 will result, and digestion proceeds rapidly. This is the reason why frequent pH determinations give a valuable index of sludge tank behavior.

Is stirring an important factor in digestion?

Parallel operating results of the two types of tanks afford a definite basis for evaluating the benefits of mechanical mixing or stirring. Two such studies have been made in this country. The following are the summarized results of a year's operation of two tanks which received a mixture of raw and activated sludge at the Chicago Sanitary District in 1931–32, as given in the Budget Report of the Chief Engineer in 1934, and as reported by Mohlman (SEWAGE WORKS JOURNAL, November, 1935):

Type of Digestion	Temp. Fahr.	Days Digest.	Sludge Per Cent Moisture		Gas Cu.Ft. per Lb. Vol. Matter Added	Per Cent Digestion Vol. Matter	B.t.u. Gas	Supernatant Liquor Per Cent Solids
			Raw	Dig.				
Plain.....	94.4°	28.4	96.2	96.2	8.9	42.1	738	.35*
Mech.....	94.8°	32.0	96.1	95.5	8.9	41.9	748	1.37*

* Later operation .42 per cent both tanks.

Keefer at Baltimore, carried on a similar study in 1932–33, the one tank being equipped with a Pruss stirring mechanism (*Waterworks and Sewage,* March 1934). These tanks received raw sludge feed once a week, which penalized the plain tank on a comparative basis. The following are the summarized results:

Type of Digestion	Temp. Fahr.	Days Digest.	Sludge Per Cent Moisture		Gas Cu.Ft. per Lb. Vol. Added	Per Cent Digestion Vol. Matter	Per Cent CO_2	Supernatant Liquor Per Cent Solids
			Raw	Dig.				
Plain	83.7°	50 (*a*) 40 (*b*)	95.0	94.1	7.3	52.8	31.8	.4
Pruss Stirring Mechanism	85.7°	50 (*a*) 40 (*b*)	94.8	96.4	8.7	56.9	32.6	.4

(*a*) 8 mo. operation.
(*b*) 4 mo. operation.

In a word, these results would not indicate any material advantage due to mechanical stirring.

What operation controls should be adopted as routine?

The operation routine should include compositing and analyzing daily fresh sludge pumpings, for moisture and volatile solids, and similar determinations should be made of ripe sludge withdrawn. For the smaller plants, one daily fresh sludge composite a week will establish the volatile content. The percent reduction of the volatile content, or the per cent increase in ash of the fresh sludge during digestion, gives a way of judging the completeness of digestion. A weekly supernatant sample should be composited for suspended and total solids to have information as to the character of the digestor overflow.

Information as to the quantity and the character of the sludge in a digestor is essential. Depth samples secured monthly at 1, 2, or 3 foot intervals in a digestor, and analyzed for solids and ash, permit following the progress of digestion and will give a valuable operation guide. Tank temperatures are best secured by using a good portable thermometer with flexible connecting tubing, marked at 2 foot intervals. Tank temperatures should be secured regularly at two week intervals. In addition, temperature of all sludge withdrawals should be obtained with a good grade thermometer, as a temperature check. pH tests of the supernatant liquid, one or two feet above the sludge line and of the sludge, should be made monthly or even oftener.

The operation records should give the amount of raw sludge added, the cubic feet of gas produced from each digestor, the CO_2 content of the gas, the amount of gas used, the amount of water circulated, and the temperature of the feed and return water to each digestor.

OPERATION OF THE CARLISLE SEWAGE TREATMENT WORKS *

By George P. Searight

Borough Manager, Carlisle, Pa.

Carlisle's Sewage Treatment Plant was reconstructed in accordance with the design of Prof. E. D. Walker, Consulting Engineer. A brief, but complete, description of this plant can be found in his article published in the September, 1934, issue of "The American City." The original plant consisted of two septic tanks, three primary and three sec-

* Presented before the Tenth Annual Conference of the Pennsylvania Sewage Works Association, State College, June 25, 1936.

ondary contact beds. This plant was reconstructed as a P.W.A. Project into our present, modern, sewage treatment works. It is of interest to note that throughout construction, sewage treatment had to be maintained. Therefore, the reconstruction of the septic tanks into settling basins was the last item of our program. This portion of the work involved pumping into both new digestion tanks an eighteen months' accumulation of septic sludge, and diverting the daily flow of sewage by means of an open wooden flume to the final basin, which was used temporarily as a primary basin.

Within two weeks we were producing gas and by June, 1935, the sludge temperature was about ninety degrees and the gas production so great that the waste gas burner, located in a separate flue in the chimney of the control house, became a roaring furnace. This fire destroyed a portion of the roof and ceiling of the control house, and was caused by the overheating of the chimney, in which the waste gas burner is situated. In making repairs, the chimney was raised four feet higher and the burner also raised, placing it one and one-half feet above the roof line.

The finished plant consists of hand-cleaned bar screens, a screenings digester, two primary settling basins, two separate sludge digestion tanks, glass covered drying beds, three circular trickling filters, a disinfection house, a resettling basin, and a control house and laboratory. The old bar screens were reconstructed to give openings between the bars of ¾ inch. Our average daily screenings amount to about two and one-half cu.ft. The screenings are hand raked and conveyed by wheel-barrow to the screenings digester, situated in a side room of the control house. This digester, supplied by the Pacific Flush-Tank Co., is a steel tank equipped with a revolving cylindrical, perforated metal drum. The top of the tank is equipped with a gas dome having an oil seal and in the bottom is situated a heating coil. Initial operating troubles included blowing of the oil seal and sludge overflowing at both open ends, which trouble generally occurred at night. The manufacturer solved this problem for us upon learning of our difficulty by supplying a motor drive and time switch, which now revolves the screen twelve minutes every hour. Our records show that about one-half of the material placed in the digester must be removed, the residue, of course, being less offensive than the undigested screenings and in better condition for use as fill, but nearly as sloppy to handle.

The primary settling basins are 100 feet long, 18 feet 4½ inches wide, and 8 feet deep, providing a detention period of slightly more than 3 hours with the present average flow. They are equipped with straight-line sludge collectors.

The digestion tanks are each 30 feet in diameter, having a total depth of 27 feet. They are equipped with 5 circular heating coils of 2–inch black, wrought iron pipe and three supernatant withdrawal pipes, to record the difference in elevation caused by the addition or withdrawal of material, have not been dependable as they do not record the elevation of the floating covers, but rather the gas pressure which accumulates in the small pipes connected to them. Each digester is equipped with a standard PFT (Downes) floating cover. From May 1, 1935, to May 1, 1936, 3,925,600 cu.ft. of gas were produced, of which only 1,755,900 cu.ft. were required as fuel; the remaining 2,169,700 cu.ft. were wasted. This gas record, however, can not be relied upon as authentic yearly data, because of the large amount of accumulated, septic sludge treated during this time in excess of that from the average flow. These tanks are operated in two steps or by the stage-digestion method. From the second stage supernatant is drawn off to the primary settling basins. The sludge temperature has been maintained at an average of 88 degrees fahrenheit.

Our nine drying beds are covered with approximately 15,000 sq.ft. of glass, and provide approximately 9,580 sq.ft. of drying area, or about 0.56 sq.ft. per capita based on the 1960 estimated population. For the removal of sludge, the bucket conveyer, suspended from a monorail, has proved very satisfactory.

The daily rate of the combined flow is recorded on a Simplex recording weir gauge. The present average daily flow is from 650,000 to 850,000 gallons per day and contains an average of 890 p.p.m. of total solids. The three trickling filters are 120 feet in diameter and have an average depth of 5 feet 4 inches of 2½ inch to 1 inch crushed limestone filtering media. Each bed is equipped with a PFT air lock type, rotary distributor. Little difficulty has been experienced with these three units other

than that of cleaning the orifices of the distributor arms. This trouble has been reduced to a minimum by installing two screens in the inlet channel ahead of the dosing chamber. These screens of one-quarter inch square mesh, are bolted to a welded frame of angle iron and placed in the channel at approximately a 45 degree angle. This has reduced the cleaning time of the distributors fifty per cent. Considering the very low head of only 13 inches, under which these distributors operate, they have performed well. Recently, however, we have encountered considerable difficulty in adjusting the arms of the distributors to prevent dragging.

Final settling is accomplished in the resettling basin, which is 55 feet long, 18 feet 4½ inches wide, and 8 feet deep, having a detention period of about one hour. This basin has hoppers at the inlet end and is equipped with a straight-line sludge collector. From this tank the sewage enters the effluent sewer and empties into the Letort Spring Run, a half mile below the plant.

We had trouble with the duplex sludge pump as the pressure from the primary tank was too great to allow the 4-inch ball valves to properly seat. This was eliminated by the installation of larger valve caps and 5½ inch diameter balls by the manufacturer. However, all the trouble was not yet eliminated as small particles, such as peach seeds, match sticks, small pebbles, etc., lodged between the balls and the seat. This trouble required the operator to clean the valves from four to six times daily, but again this difficulty was eliminated by the manufacturer by enlarging the head receptable to allow the balls to go up farther, thus, providing a larger opening. This pump is also equipped with a Sterling enclosed, vari-speed motor and a Veeder counter. A centrifugal sludge pump is for stand-by purposes, and has only been used for trial purposes.

The upper floor of the control house includes a hall leading from the basement stairs past the main entrance, a lavatory, and a fully equipped laboratory. Four Bristol recording thermometers are installed in the hallway.

Operation data is now recorded by the operators on three mimeographed weekly sheets placed at points about the plant that are centrally located to the data requirements. These are headed: Disinfection House Record, Control House Basement Record, and Control House Main Floor Record. From these records and laboratory results, the weekly report for the Pennsylvania Department of Health is compiled.

The Disinfection House Record consists of amount and rate of chlorine used, the time sludge collector runs, pump counter reading, and to what unit pumped. The Control House Basement Record records meter readings of gas produced by each digester, gas consumed as fuel and gas wasted, meter readings of hot water circulated to each digester, temperature of the return heating water from each digester as read from an installed indicating thermometer, pounds of lime used and for what purpose use was made, pump counter reading, and purpose for which pump was used. The data recorded on the Control House Main Floor Record is: weather conditions and temperature, number of times bar screens are cleaned, the amount of screenings removed to the screenings digester, the amount of material removed from the screenings digester, temperature of the return heating water from the screenings digester, number of primary settling basins in use, time sludge collectors are run, trickling filters in use, machinery greased, repaired, or inspected, and sludge placed on or removed from the drying beds as to the depth, color, and odor. On each of these sheets sufficient space is available for remarks of any other work, break-downs, or unusual occurrences to be reported. These forms are filed at the desk together with the weekly charts from the various recording instruments which record the quantity of sewage passing through the plant, the temperature of sludge in each digester, the temperature of the feed and return heating water to each digester, and the elevation of each floating cover.

From the above information the most important operating data are transferred to a loose leaf record book. This record is in a compact and concise form and aids in comparing results and operation from time to time. Laboratory results are also recorded in this book.

The only other available laboratory results that have not been referred to are those of relative stability and digested sludge analysis. The relative stability of the stream above and below the plant, the effluent of each trickling filter, the final effluent of the

plant, are all above 98 per cent. The digested sludge drawn to the drying beds during the past month has had an average of 46 per cent ash content, computed on the dry basis.

Carlisle's Sewage Treatment Plant, which is under the direct supervision of the Borough Manager, is operated by two full time operators, each working 9 hours a day, 6 days a week and 2 hours on Sunday. More than half of the time of one man is taken up in caring for the grounds and buildings. The operation of the plant and all laboratory work is in charge of the Assistant Engineer, who gives approximately one half of his time to this work.

Editorials

FLOCCULATION

The flocculation of the colloids in sewage is probably the most important phenomenon connected with the purification of sewage. Removal of settleable solids involves no process of particular scientific interest as it is usually accomplished by slowing the velocity of the flowing sewage sufficiently to permit the coarser particles to subside. The cloudy liquor that is discharged, however, belies its clarified appearance, for it still contains two-thirds of the oxygen consuming matter of the original sewage. This is no new discovery, but was known to be true more than fifty years ago, and efforts were directed toward the flocculation and removal of the remaining unsettleable solids.

Chemicals were used for flocculation long before the present century. A review of these developments was published in the committee report on chemical precipitation, THIS JOURNAL, November, 1935. Great varieties and complex mixtures of chemicals were used without any clear understanding of the principles governing their action.

In the nineties it was realized and demonstrated, mainly in England and at the Lawrence Experiment Station, that flocculation might be accomplished by biological means. There was as yet no attempt to explain the results by principles of physical or colloid chemistry. Hofmeister had thrown some light on the action of chemicals, but it was not until the decade 1900–1910 that the flowering of the colloid fundamentalists occurred, marked by the work of Perrin on dialysis, Freundlich on adsorption, von Weimarn, Ostwald and Zsigmondy on the inorganic sols and Dunbar, Travis and Dibdin on the practical application of the principles of colloid chemistry in sewage treatment. From 1905 to 1915 a large amount of research was carried on, particularly in England, concerning the nature of colloids in sewage and methods by which they might be flocculated and removed. Fowler at Manchester, O'Shaughnessey at Birmingham, and others published valuable papers in this decade on the determination of colloids in sewage and methods for their removal. However, interest lagged from 1915 to 1925, except for study of the activated sludge process, and even here the true significance of biological flocculation was hardly recognized.

During the past ten years there has been a reawakened interest in flocculation of sewage colloids, both by chemicals and biological means. Experimental work on aerated colloiders, Buswell's nidus racks, the use of surfaces of many types, plus air, and recently the study of high-rate biological filters—all have contributed to the advancement of sewage purification by flocculation of solids. The recent revival of chemical treatment of sewage has resulted in the development of mechanical flocculators which materially improve the process of floc-building and result in a more highly purified effluent, provided the floc is not broken up when introduced into the settling tank. The use of such flocculators demands careful design of conduits and entrance weirs or ports in the settling tank in order not to lose some of the advantages of the flocculator. There has not been sufficient experience with flocculators in sewage treatment to determine which of the various mechanical types, or the use of air, may be most efficient. Likewise the time required for different sewages may vary from fifteen minutes to one hour. It is surprising to discover that thirty minutes or more may be necessary to obtain maximum flocculation.

Recent work at Coney Island, Cedar Rapids and elsewhere indicates that use of flocculators without chemicals may result in quite appreciable improvement in quality of effluent, by coagulation and removal of sewage colloids merely by contact. This action verges on the field of action of activated sludge, but from a practical standpoint it means that it may be desirable to operate flocculators in plants designed for seasonal chemical treatment even when chemicals are not added.

There are many possibilities ahead for the practical utilization of flocculation. In the chemical field the use of clays, bentonite, silts and new combinations of well-known

chemicals may produce surprising results. In the biological field the ability of the high-rate trickling filter to flocculate sewage colloids has been noted by Levine, Jenks, Halvorson and Mohlman in their recent papers in THIS JOURNAL. The study of flocculation is fascinating although somewhat elusive, because the results with different sewages or with the same sewage under various climatic or industrial conditions may vary so widely. Here is a broad field for fundamental research. Dr. Rudolfs has attacked it and we have had several papers from his laboratory on this subject. It is to be hoped that the problem will appeal to other research workers as one likely to yield fruitful and practical results.

F. W. M.

CALVERT LEAVES INDIANAPOLIS SEWAGE PLANT

The news that Cecil Calvert is leaving the Indianapolis Sanitary District, to return to the Indianapolis Water Company as chemical engineer, will be regretted by the many friends of Mr. Calvert in the sewage treatment field. For ten years he has operated the Indianapolis activated sludge plant with marked successs and efficiency in spite of limited, in fact niggardly, budget appropriations. Many interesting and valuable special investigations have been carried on under his direction, such as studies of industrial wastes, the effect of chlorine on sewage effluents, the aeration of sewage without returned activated sludge, the oxygen demand of activated sludge, the grinding of garbage prior to disposal in sewers, and the effect of fluctuations in sewage flow and strength on its disposal. Most of these reports have been published in THIS JOURNAL, and the results have been of great value to other students of sewage disposal.

Even greater than the loss of Mr. Calvert's scientific contributions will be the loss of his genial presence at sewage works meetings and his welcome visits to other laboratories and other treatment works. As an organizer of successful meetings, Mr. Calvert has no peer, as demonstrated by his recent handling of the meeting of the Central States Sewage Works Association in Indianapolis.

The Sewage Works Federation's loss is the Water Works Association's gain. Indianapolis is fortunate to have retained Mr. Calvert in another type of sanitary work. His friends in the sewage treatment field offer their best wishes for success in his new job, but hope he will still retain his interest in the problems of sewage disposal.

F. W. M.

Proceedings of Local Associations

NEW YORK STATE SEWAGE WORKS ASSOCIATION

Fall Meeting, Geneva, N. Y., Oct. 9–10, 1936

Amid the marvelous autumn coloring along the beautiful Finger Lakes at Geneva, N. Y., the New York State Sewage Works Association held its Fall Meeting on October 9 and 10, 1936, at the Hotel Seneca. There were registered 165 members and guests including 25 ladies.

Following registration at the City Hall where the technical sessions were held on Friday, the gadget display was inspected. This was the first gadget competition of the association, and although there were only eight or nine entries, the interest shown in the various sewage works appliances developed by operators indicates that the second competition will require considerable space.

A brief business meeting was held at which it was announced that steps were being taken to provide for an increase of fifty cents in the annual dues of active members to cover the proposed increase found necessary to put the *Sewage Works Journal* on a self supporting basis. Special attention was called to W. D. Hatfield's section on "Operators' Reports and Suggestions" in the *Sewage Works Journal* inaugurated in the March issue, the purpose of which is to aid plant operators by the exchange of information, operating kinks, abstracts of annual reports, etc. Items of apparent minor importance to one operator may be of major interest to fellow operators.

At the technical session Friday morning, W. A. Ryan, Sanitary Chemist of Rochester, presented a paper on "Experiences with Activated Carbon in Sewage Treatment"; Charles W. McBreen, Chief Engineer of Rockland State Hospital, gave a paper on "Problems in Sewage Treatment at State Institutions," the discussion on which was opened by Henry Ryon, Senior Sanitary Engineer, State Department of Public Works.

President Linn H. Enslow presided at the luncheon and introduced C. A. Emerson, Chairman of the Federation, and the guest speaker, Hon. Henry T. Maxwell, Mayor of the City of Geneva.

At the afternoon session M. F. Abrams of Wailes Dove-Hermiston, spoke on the "Protection of Sewer Pipe and Concrete," the discussion on which was opened by Stanley T. Barker, Assistant Sanitary Engineer of the State Department of Health. George W. Moore, District Sanitary Engineer of the State Department of Health, Rochester, gave his experiences in the "Control of Sewage Plant Odors," and K. A. Keirn of Wallace and Tiernan Company, Buffalo, opened the discussion on this subject. J. W. Brennan, Superintendent of Public Works of Geneva, gave an excellent brief history of the water supply system and the sewerage system of the city, and E. A. Marshall, Superinten-

dent of the sewage treatment plant of Geneva, spoke on the operation of the new plant and some of the problems that had to be overcome.

Friday noon the ladies enjoyed luncheon at the Geneva Country Club overlooking Seneca Lake and then in automobiles visited a number of points of interest in and around Geneva.

Friday evening following the usual informal banquet, the group were entertained by the excellent quartette of the Hobart College Glee Club and their director, and also with two groups of dance numbers artistically performed by the pupils of the Helen Finnerty dance studio of Geneva. Following the entertainment dancing was enjoyed until midnight.

Saturday morning 84 men participated in the now famous Sunrise Breakfast and discussed their problems in the Question Box conducted by Morris Cohn and Charlie Agar. This was a record attendance. Announcement was made of the results of the balloting in the gadget competition. First award went to John Woodford, retired Superintendent of Sewers, Ithaca, "Homemade Sludge Grinder"; second award to C. G. Anderson, Superintendent of Sewerage, Rockville Center, "Homemade Laboratory Sludge Centrifuge"; and third award to John Woodford, Ithaca, "Automatic Air Release Valves." The awards will be in the form of framed certificates.

Under police escort an automobile caravan of some thirty cars inspected the new Geneva sewage treatment works. Although the meeting officially adjourned at noon, a large group visited the Auburn sewage treatment works, now under construction, and the Newark sewage treatment works.

The next meeting of the Association will be the Eighth Annual Meeting in New York City, January 21, 22, 23, 1937.

A. S. BEDELL, *Secretary-Treasurer.*

CANADIAN INSTITUTE ON SEWAGE AND SANITATION

Third Annual Convention, Toronto, Ontario, Oct. 1–2, 1936

The third annual convention of the Canadian Institute on Sewage and Sanitation was held at the Royal York Hotel, Toronto, on October 1 and 2, 1936. This followed immediately after the Public Works Congress, and because of the relationship of the two programs was a convenient arrangement.

Another successful meeting of the Institute was recorded this year. The total registration was 120, and keen interest was displayed in the papers and the discussions. The papers had the following titles and authors: "A Symposium on Sludge Disposal" headed by Grant R. Jack, East York, J. F. MacLaren, Toronto, and J. S. Pecker, New York; "Sewage Disposal Practices in Michigan" by Col. E. D. Rich of Lansing; and "Design and Operation of Sewage Disposal Plants for Small municipalities" by W. B. Redfern, Toronto. Considerable time was devoted to a round table conference on general problems in sewage disposal.

The election of officers for the Institute resulted in the following executives: President, Grant R. Jack, Commissioner of Works, East York Township, Ont.; Past President, Geo. H. Ferguson, Chief Engineer, Department of Pensions and National Health, Ottawa; Vice-President, Norman J. Howard, Director of Water Purification, Toronto; Trustees, T. J. Lafreniere, Chief Engineer, Bureau of Health, Province of Quebec, Montreal, and W. C. Miller, City Engineer, St. Thomas; Secretary-Treasurer, A. E. Berry, Ontario Department of Health, Toronto.

The secretary reported a gain in membership during the year, with the total now reaching 70. A proposal of interest to all members was discussed at the business session, whereby it is proposed to initiate an information exchange, somewhat similar to that conducted by the Canadian Section of the A. W. W. A. Through this, data of various kinds would be tabulated and distributed in loose leaf form to the members.

For an inspection trip the delegates were taken to the North Toronto activated sludge plant. In addition to seeing the regular operation of the plant they were enabled to see a demonstration of sludge dewatering by a centrifuge operated by the Canadian Centrifugal Corporation.

ALBERT E. BERRY, *Secretary-Treasurer.*

CENTRAL STATES SEWAGE WORKS ASSOCIATION

Ninth Annual Convention, Indianapolis, Indiana, October 29–30, 1936

The Ninth Annual Convention of the Central States Sewage Works Association was held at the Antlers Hotel, Indianapolis, Indiana, on October 29–30, 1936. The total registration was 127, made up of visitors from many states and including quite a number from Minneapolis.

The meeting was called to order Thursday morning by President O. M. Leonard. The morning meeting was rather informal. It included a report by Mr. W. W. De Berard on the status of the Sewage Works Federation and the question of financing the *Sewage Works Journal.* After some discussion of Mr. De Berard's remarks the matter of an increase in dues from $1 to $1.50 was referred to the Executive Committee, which later approved this increase with the suggestion that the matter be referred to the membership of the Central States Association.

An informal luncheon followed the morning meeting and at 1:00 P.M. the following program was presented.

THURSDAY AFTERNOON SESSION,

Vice-President H. E. Babbitt, Presiding

"The Kokomo, Indiana, Sewage Plant," Russell B. Moore, Consulting Engineer, Indianapolis.

"Some Fundamental Factors Concerned in the Operation of Trickling Filters," H. Orin Halvorson, Ph.D., Associate Professor, Department of Bacteriology, University of Minnesota.

"One Year's Operation of an Experimental High-Rate Trickling Filter," F. W. Mohlman, Chief Chemist, Sanitary District of Chicago.

"Taking a Look at Sewage Treatment (Yesterday-Today-Tomorrow)," Linn H. Enslow, President, New York State Sewage Works Assn.

The annual banquet and entertainment was held at 6:30 P.M. The program consisted of a floor show, a group of delightful songs by Mrs. Arthur B. Morrill and a stimulating address by Dr. Thurman B. Rice of the Medical School of Indiana University, who discussed the need for advancement in problems of mental hygiene and a common sense viewpoint toward the problems of modern life. Chairman Calvert, in his usual delightful way, introduced visiting members to the Association, prefacing his remarks by some personal anecdotes.

The Friday morning technical session consisted of the following program.

FRIDAY MORNING SESSION,

Dr. M. Starr Nichols, Presiding

"The Gas Engine Installation at Aurora, Illinois," Walter A. Sperry, Supt., Aurora Sanitary District.

"Biochemical Oxidation by Activated Sludge," C. C. Ruchhoft, P. D. McNamee and C. T. Butterfield, Principal Chemist, Asst. Chemist, and Principal Bacteriologist, U. S. Public Health Service.

"Influence of Phosphorus and Nitrogen on Five-Day Biochemical Oxygen Demand," W. L. Lee and M. Starr Nichols, Asst. Chemist and Chief Chemist, Wisconsin State Laboratory of Hygiene.

"Sludge Digestion—The Effect of Influenced Bacterial Population," Paul W. Richards, Asst. Supt., Indianapolis Garbage Reduction Plant.

At the special luncheon held Friday noon, reports of committees were received and announcement was made that the annual prize for the best paper presented at the 1935 meeting had been awarded to Mr. Arnold J. Beck, Principal Sanitary Chemist of the Sanitary District of Chicago, for his paper on "Diffuser Plate Studies," published in the *Sewage Works Journal* for January, 1936, p. 22. The awards for the Gadget Contest were also announced and the description of the gadgets and their inventors will be given in the next issue of the *Sewage Works Journal.*

A very cordial invitation was received from Minneapolis-St. Paul for the 1937 meeting. (This request has been accepted by letter ballot of the membership.)

Election of officers next took place, resulting in the following elections:

President: H. E. Babbitt, Urbana-Champaign, Illinois.
1st Vice-President: F. M. Dawson, Iowa City, Iowa.
2d Vice-President: George J. Schroepfer, St. Paul, Minnesota.
3d Vice-President: B. A. Poole, Indianapolis, Indiana.
Secretary-Treasurer: Gus H. Radebaugh, Urbana-Champaign, Illinois.
Representatives to the Board of Control: James L. Ferebee, Milwaukee, Wisconsin; W. W. De Berard, Chicago, Illinois.

The final session of the meeting Friday afternoon included the following papers.

FRIDAY AFTERNOON SESSION

"Madison Improves Its Sewerage System," H. O. Lord, Chief Engineer, Madison, Wisconsin, Metropolitan Sewerage Commission.
"Sewage Plant Construction With W.P.A. Labor," M. W. Tatlock, Supt., Dayton, Ohio, Sewage Treatment Plant.
"Additions to the Milwaukee Sewage Treatment Works With the Aid of P.W.A.," James L. Ferebee, Chief Engineer and General Manager, Milwaukee Sewerage Commission.
"Janesville in the Rock River Clean-up Program," Joseph Lustig, City Engineer, Janesville, Wisconsin.
Unfinished Business.
Adjournment.

F. W. MOHLMAN.

CALIFORNIA SEWAGE WORKS ASSOCIATION

Ninth Annual Conference, Santa Monica, September 10–11, 1936

One hundred twenty-five members of the California Sewage Works Association met with the League of California Municipalities at Santa Monica, California, on September 10th and 11th in the Association's ninth annual conference. Situated in the heart of the Los Angeles metropolitan area, Santa Monica offered an unusually good starting point for the Association's customary inspection caravan on their first day of meeting. Proceeding from the convention city at 8:30 in the morning, members assembled at the extensive Hyperion screening works of the City of Los Angeles, viewed the present plant and equipment in operation and proceeded thence to the Joint Disposal Plant of the Los Angeles County Sanitation Districts, where members were shown the activated sludge and separate digestion works.

Continuing, the caravan advanced to Camp No. 2 on the line of the 6.2 miles tunnel being constructed by the County Sanitation Districts to convey effluent from the joint disposal plant to ocean disposal at White's Point, and were shown the tunnel construction.

Luncheon was served in the Palm Gardens adjacent to the site of the ocean outfall at White's Point and an inspection of the ocean pipe line and tunnel construction was made. Thence the caravan journeyed to the new Terminal Island treatment works of the city of Los Angeles,

following which the screening and incineration plant of the city of Long Beach was viewed—the caravan returning to Santa Monica in time for registration and the annual dinner meeting.

Guest speaker for the dinner meeting was the Honorable A. E. Stockburger, Director of Finance for the State of California. Mr. Stockburger reviewed the financial status of the state and gave the members a very lucid and timely explanation of the state's resources and the method and manner in which state funds are tagged and expended by legislative enactments. He indicated clearly the limited amount of money which is available to the state agencies for purposes other than that for which it is specifically collected; that although the biennial budget of the State of California may run into hundreds of millions of dollars, there are but few of those millions over the expenditure of which the state officials have discretionary powers, and that request for state funds for sewage research or other purposes must be influenced by the very narrow margin of excess funds which the state may have.

The technical session, the morning of September 11 held in conjunction with the city engineers' and street superintendents' section of the League was well attended. Papers were presented by C. G. Smith and C. C. Kennedy, outlining new structures and proposed changes in the City of Los Angeles' extensive sewer system and disposal works and Stockton's proposed plans for reconstruction of its sewage treatment plants, respectively. Motion pictures were offered by the Chairman, depicting preliminary investigations and construction work upon the County Sanitation Districts' outfall tunnel and pipe line.

In the afternoon Harry N. Jenks of San Francisco presented a comprehensive picture of his applied innovations to the trickling filter, while San Diego's assistant city engineer, B. D. Phelps, outlined proposed improvements in sewerage facilities in his city. The meeting concluded with committee reports on operators' schools, voluntary registration of operators, safety regulations for sewer maintenance employees, and proposed and current legislation affecting sanitary works and workers; closing with election of officers for the year 1937. The following officers were unanimously chosen:

President: E. A. Reinke, Berkeley.
First Vice-President: R. F. Goudey, Los Angeles
Second Vice-President: A. B. Bell, San Francisco
Secretary-Treasurer: R. R. Ribal, Oakland
Director, Five-year term: A. M. Rawn, Los Angeles
Director, Two-year term: J. I. Ballard, San Francisco
Member, Board of Control: C. G. Gillespie, Berkeley.

FRED D. BOWLUS, *Secretary-Treasurer.*

Reviews and Abstracts

H. W. Streeter

RESEARCHES ON POLLUTED WATERS. CONSUMPTION OF OXYGEN AND CAPACITY FOR PURIFICATION (RECHERCHES SUR LES EAUX POLLUÉES. CONSOMMATION D'OXYGENE ET CAPACITÉ D'ÉPURATION)

By André Leys

Librairie J.-B. Baillière & Fils, 19 Rue Hautefeuille, Paris, 1936

In certain parts of France, notably the northern region, the problem of stream pollution has become particularly acute. As the author has found no references in the French literature bearing on the quantitative measurement of the intensity of pollution and capacity for self-purification of polluted streams, he has prepared this comprehensive monograph from a series of British and American sources, consisting mainly of publications of the British Royal Commission on Sewage Disposal, the U. S. Public Health Service and the Sewage Works Journal.

In the opening chapter, the author traces the historical development of the measurement of biochemical oxidation in polluted waters, beginning with the work of Frankland in 1868–70 and of Dupre in 1884–85, and extending through the later studies of Adeney and others in Great Britain and of Phelps and his colleagues in the United States. After emphasizing the practical importance of the first stage of oxidation, he deals with the basic mathematical equation for the rate of oxidation, as developed by Phelps (1912), noting its relationship to the monomolecular reaction formula of Wilhelmy. Denoting this equation as Phelps' rule, he then proceeds to discuss the methods of calculating the total oxygen demand and rate of oxidation, noting how the latter is influenced by bacterial multiplication and by variations in temperature. In describing various sources of error in this determination, he points out the effect of "immediate" and retarded oxygen demands, the latter being due to the presence of insufficient initial numbers of bacteria or of antiseptic substances.

In Chapter II are explained the details of laboratory tests for biochemical oxygen demand, and in Chapter III, their application to measuring biological oxidation in natural streams. In the latter connection, he notes that measurements conducted by him and his co-workers in the River Aa, a polluted tidal stream of northern France, have confirmed the applicability of Phelps' rule to natural watercourses.

The concluding chapter (Chapter IV), deals with the reaeration capacity of natural streams and its quantitative measurement. The rate of atmospheric reaeration is discussed, together with its mathematical expression (see This Journal, VII, 3, May, 1935), and also the influence of biological photosynthesis, of which the author gives an example based on his personal observations. The resultant oxygen equation of Streeter and Phelps (1925) is then described in detail, together with the determination of the critical minimum oxygen point. In this connection he refers to the results of his measurements in the River Aa and explains by means of computations the application of the formulas to these results. Extending this application, he then shows how to calculate for a given set of conditions the limiting pollutional load on the watercourse which may be consistent with maintaining a specified minimum reserve of dissolved oxygen.

At the end of the monograph, the author states, in brief, the following conclusions:

1. His researches have confirmed that the decrease in concentration of organic matter, in the incubation of polluted water in the presence of an excess of dissolved oxygen, conforms to Phelps' rule, if the precautions described in Chapter II are observed.

2. Taking account of all the factors of disturbance in natural watercourses (tributaries, intermediate pollution, suspended matter and fermentation of bottom sludge deposits), he has verified observationally that the consumption of oxygen in such watercourses, as in the laboratory, follows the rule of Phelps.

3. From the two preceding conclusions it may be deduced: (*a*) that the laboratory determination of the B.O.D. over a given time permits, in accordance with Phelps' rule, the calculation of the total B.O.D. for the first stage of oxidation, and (*b*) that this determination is the most rational method of measuring the pollution of water, being based, in effect, on the reproduction, *in vitro,* of the phenomenon of self-purification in nature.

4. He has confirmed that the observation of watercourses can be accomplished by comparison of the results of first-stage B.O.D. determinations at two points, A and B, in the stream, conveniently chosen and separated from each other by a distance corresponding to a time of flow of the order of one to three days. In interpreting the results, it is necessary to take account of various disturbing factors (tributaries, intermediate pollution, sedimentation, sludge deposits and nitrification).

5. The method of calculating reaeration, as studied by Streeter and Phelps on large American rivers, is applicable to watercourses of lesser size, as demonstrated by the author by a series of observations in the small canalized river, the Aa. It is possible in many cases, by using this method, to calculate in advance the pollution which can be tolerated in a watercourse, without prejudice to hygiene.

6. The strictly biological methods of studying water pollution, based on the study of the fauna and flora, have been previously recognized as important. Although their interest is incontestable, it is evident that these methods never can have the quantitative precision and the general application such as is presented by the "biochemical" method, based on the consumption of dissolved oxygen. When the law of oxygen consumption is combined with the law of reaeration, it is possible to foresee in a truly remarkable way the progress of self-purification in natural streams.

A comprehensive list of references is appended to the monograph.

H. W. STREETER

NATIONAL LEGISLATION ON STREAM POLLUTION

Hearings before a Subcommittee of the Committee on Commerce, United States Senate, 74th Congress, 2d Session, on Bills S3958, S3959, S4342 and S4627. (Relative to prevention of pollution of navigable waters and other matters.) U. S. Govt. Printing Office, Washington, 1936. 492 pp.

This document contains a verbatim report on hearings of four Senate bills designed to prevent pollution of navigable waters of the United States (S3958), to amend previous Acts relative to the deposit of refuse in and oil pollution of such waters (S3959), and to create a division of stream pollution control in the Bureau of the Public Health Service (S4342 and S4627). Owing to its voluminous nature, no brief abstract of the document is possible; hence only a few notes can be given here concerning the general nature of the bills and of the testimony introduced in connection with them.

Bill S3958 provides for making the National Resources Committee a permanent establishment of the United States and for its composition as an interdepartmental body. It also provides for cooperation with State agencies in unifying laws and policies relative to water pollution control, for interstate compacts, for studies and surveys, for establishment of sanitary water districts, with district boards, for loans and grants to States and municipalities for sewage treatment works, and for injunction proceedings to abate pollution.

Bill S3959 provides for the broadening of applicability of previous Acts prohibiting the deposit of refuse in streams and oil pollution of navigable and coastal waters, so as to include the discharge of sewage, acids and sludge, and oil pollution of tributary waters.

In the hearings on these two Bills, representatives of various industries and of State health, fisheries, legal and water conservation agencies testified as to the seriousness of the problems resulting from water pollution and as to the legal and financial difficulties in-

volved in undertaking to deal with them through legislative measures. The present situation in many parts of the country was described in detail, and likewise the laws which have been enacted in various States to regulate water pollution. In general, representatives of both industries and States expressed opposition to the centralized Federal control features of these two Bills and their advocacy of greater moderation in these respects. A large amount of valuable statistical information was given concerning the status of water pollution and efforts to abate it in various parts of the country.

Considerably more moderate in their proposals were Bills S4342 (introduced by Senator Copeland) and S4627 (introduced by Senator Barkley), providing for the creation of a division of stream pollution control in the Public Health Service. In S4627, which was stated as having the endorsement of the State and Territorial health officers, interstate cooperation in dealing with stream pollution would be aided and encouraged through the creation of a division in the Public Health Service especially designed to promote such cooperation. This division would be authorized to promote interstate compacts for pollution abatement; to collect and disseminate information; to conduct studies and investigations on requests from State authorities; to prepare and publish reports, with recommendations, and to furnish such assistance to State agencies as may be authorized by law. An important feature of this Bill is a provision for public grants in aid and/or loans for the construction of remedial treatment works, where approved by the State and by the Public Health Service. Similar aid also may be extended to private waste-producing industries, under the same general restrictions. Annual appropriations are authorized up to $300,000 for the expenses of the new division, and up to $700,000 (for ten years) for expenses of State health departments in carrying out stream pollution control activities.

In support of this Bill appeared representatives of chambers of commerce, industry, technical and trade associations and State health and conservation departments, the general tenor of their remarks indicating endorsement of its more moderate provisions and especially those for Federal encouragement and assistance of interstate cooperation. Several active proponents of the Bill appeared from Ohio River Basin States, pointing out the seriousness of the water pollution situation in this area and the need for a concerted attack on the problem.

H. W. STREETER

EXPERIMENTAL SEWAGE FILTERS AT THE WUPPERTAL-BUCHENHOFEN TREATMENT PLANT

BY DR.-ING. MAHR AND ING. LERNER

Gesundh.-Ing., 59, 8, 1936

The sewage from more than 200,000 people and the wastes from a large industry are discharged into the Wupper River, a small stream, all at one point. The dilution is ordinarily about 1 to 4 and in dry years considerably less. The present settling tanks provide insufficient purification and no satisfactory method for additional treatment of the sewage and waste has been found. Biological purification by the activated sludge process is possible but very expensive because of the industrial wastes. An experimental rapid sand filter was constructed for use preliminary to the activated sludge process. In the filter bottom, separate pipes were used for the distribution of air and water, the water pipes being fitted with nozzles and the air pipes having holes about 0.2 in. in diameter, spaced about 2 in. apart. Over these pipes was placed first a 12-in. layer of gravel 0.3 to 0.6 in. in diameter, then 6 in. of gravel 0.15 to 0.3 in. in diameter and above that a layer of sand about 28 in. deep. The wash water troughs were placed at least 10 in. above the sand.

Using sand 3 to 4 mm. in size, filter runs of 40 to 50 hrs. were obtained, but the efficiency was very low. With sand 2 to 3 mm. in size, the oxygen consumed value was reduced about 13 per cent, with a velocity of filtration of 11.8 ft. per hr. and about 21 per cent at velocities of 8.8 and 5.9 ft. per hr. At the highest velocity the filter runs were about 20 to 25 hrs.

Using sand 1 to 2 mm. in diameter the oxygen consumed value was reduced about 20 per cent with a filtering velocity of 11.8 ft. per hr., about 25 to 30 per cent with a velocity of 8.8 ft. per hr. and as much as 35 per cent with a velocity of 5.9 ft. per hr.

The filters were washed with air and raw water. The wash water averaged about 36 to 49 gals. per sq. ft. or about 1 to 6 per cent of the filtrate and the air about .026 to .039 cu. ft. per sq. ft. per second. The velocity of the wash water through the sand was about 10 to 16 ft. per hr. and the duration of wash about 20 minutes. At first the wash water was very badly polluted and contained about 200 c.c. settleable solids per liter. The filter is generally washed until the settleable solids are reduced to 10 c.c. per liter and a small amount of sludge is allowed to remain on the filter. At the beginning of washing some odor is often observed but no difficulties have arisen in several months' operation. The solids in the wash water settle well but the settled liquor always remains black and generally is about twice as strong as the sewage. In the filter the sewage particles did not remain on the surface but were equally distributed throughout the bed.

An experimental activated sludge plant which had a capacity of 2900 gallons was used for about four months. An aeration period of at least 10 to 12 hrs. was required for settled sewage but for filtered sewage the aeration period was reduced to about one-half.

G. P. EDWARDS

MUNICIPAL SANITATION AND THE NATIONAL SUPPLY OF RAW MATERIALS

VI. Sewage Sludge Utilization

BY DR.-ING. A. HEILMANN

Gesundh.-Ing., **59**, 124, 1936

In 1931 Munich agreed to furnish the Garching District and the Garching Waste Land Association with a minimum of 882,500 and a maximum of 1,285,000 cu. ft. of wet sludge per year. In 1932, at their request, the amount was increased to 1,412,000 cu. ft. and in 1933 1,334,000 cu. ft. of wet sludge were pumped to the Garching Waste Land Association. The section north of Munich where the treatment plant is located consists of poor gravel land, which can be improved by the use of digested sludge but until recently the high cost of transportation has made this impracticable.

A reinforced concrete tank of 12,350 cu. ft. capacity was erected at the treatment plant to store digested sludge. A field railroad, which consists of a locomotive with a Diesel engine and 24 cars, each having a capacity of 79.5 cu. ft., can be loaded with sludge from the tank in 7 to 8 minutes. The track, which can be moved as desired, is laid through the district to be furnished with sludge and the sludge can be discharged on both sides of it through swinging pipes. With this equipment as much as 12,350 cu. ft. of sludge can be moved per day. At a distance of 2 to 6 miles from the plant about 2900 acres are available for the disposal of sludge, each acre requiring about 3570 cu. ft. With an annual sludge production of about 2,471,000 cu. ft. as much as 690 acres can be fertilized. One sludge fertilization of this kind lasts four years. Experiments show that in freshly fertilized fields vegetables requiring hoeing are best and, in the second year, good results are obtained with wheat if nitrogen is added. Proper fertilization with sewage sludge requires from 3400 to 4200 cu. ft. per acre.

G. P. EDWARDS

THE INFLUENCE OF SLUDGE DIGESTION ON THE GERMINATION OF WEED SEEDS

BY DR. K. VIEHL

Gesundh.-Ing., **59**, 38, 1936

As a fertilizer digested sludge has many advantages over fresh solids. The organic substances are well broken down, increasing the amount of fertilizing substances, and

the nitrogen losses during digestion are less than during the aerobic decomposition in the ground.

To determine the influence of sludge digestion on the germinating power of weed seeds the following seeds were added to a liter of digested Imhoff sludge, which had been mixed with two liters of raw sludge from the Leipzig treatment plant:

500 tomato seeds
500 hemp seeds
700 beet seeds
700 canary grass seeds
500 millet seeds
700 lettuce seeds

Lime was added to bring the pH to 7.0 and 250 grams of the mixture were removed and mixed with earth. Care was taken that the earth contained no seeds and that none was introduced by air. The sludge was allowed to digest at room temperature and lime was added as necessary to maintain the pH between 6.5 and 7.5.

After 4, 8, 10, 14 and 17 weeks 250 grams of thoroughly mixed sludge were combined with earth. The number of plants which germinated are shown in the following table:

Digestion Period Weeks	Tomato	Beet	Canary Grass	Millet	Lettuce	Starwort	Grass	Other Plants	Total Excluding Tomatoes
0	32	38	48	29	24	34	4	26	203
4	25	17	16	3	0	4	1	3	44
8	28	1	0	0	0	0	0	3	4
10	25	0	0	1	0	0	0	0	1
14	18	0	0	0	0	0	0	0	0
17	12	0	0	0	0	0	0	0	0

The number of tomato plants was practically unchanged in 10 weeks but decreased about 60 per cent in 17 weeks. Only about 20 per cent of the other seeds remained after 4 weeks digestion and, after 8 weeks, except for the tomatoes, practically none remained. Apparently the hemp seed was too old to grow, even at first, but a microscopic examination after 10 weeks showed that the cell structure had not been destroyed. After 17 weeks they were soft and contained bacteria but apparently they were as resistant as tomato seeds. The experiments indicate that plant seeds, except for tomatoes and other thick shelled seeds, soon become incapable of germination.

G. P. EDWARDS

SEWAGE CLARIFICATION PLANTS IN ENGLAND

BY DR.-ING. K. IMHOFF

Gesundh.-Ing., 59, 106, 1936

In Germany and North America it has long been recognized that sewage plants can be odorless only when the sewage is kept fresh and that detention periods in settling tanks should be about 2 hours. In contrast to this the Report of the Royal Sewage Commission of 1908 recommended a detention period in settling tanks of 10–15 hours for dry weather flow and, with chemical precipitation, 8 hours. The total detention period in all the tanks, including those used for storm water, is 16–21 hours in England as compared with 2–3 hours in Germany and North America. In 27 years this difference of opinion has not changed, with the result that the development of settling tanks in England is quite different from that in other countries. For example, Imhoff tanks,

which are used extensively in Germany and North America, are practically unknown in England, since they cannot be built where such long detention periods are used. Nor is the new type continuous sludge removal equipment employed because of its high cost in the large settling tank. English settling tanks are commonly cleaned by hand. Consequently, sludge is removed only when absolutely necessary, with the result that odor from sewage and sludge cannot be avoided.

Since 1912 Watson has handled the sewage and sludge at Birmingham without odor by keeping the sewage fresh, digesting the sludge in a special digestion tank and then drying it on sand beds. The fresh sludge is innoculated with well digested sludge before being pumped to the digestion tanks, which are arranged in two stages. The gas is collected from the first stage tanks by floating covers and the sludge from the second stage is used for innoculating purposes.

The activated sludge plants at Mogden, near London, and Birmingham (Coles-Hill) are examples of the newest type of English plant. In both of these plants a compromise has been reached between the new methods of sludge removal and long detention periods. The settling tanks are divided into two stages. In the first stage, where most of the sludge settles, the tanks are circular and are equipped wih continuous sludge removal equipment. The tanks in the second stage are rectangular and sludge removal equipment of the Leipzig type is used. The bottoms of the circular tanks are hopper-shaped with a 30 degree slope and storage space for sludge is provided. The detention period in the newest plants is about 8–12 hours and, including the storm water tanks, 20–24 hours.

Four principles guide the English engineers in making calculations for a settling tank:

1. Industrial sludge often cannot be digested. For example, at Bradford the sewage contains large quantities of waste from wool washing and dye industries. Here the fats are removed and the sludge made into fertilizer. The settled sewage is purified in trickling filters and in this case short detention periods are undesirable. Long detention periods produce a concentrated sludge with water content of about 80 per cent.

2. Wastes which are poisonous, acid or in other ways injurious to biological processes should be allowed to mix with sewage for as many hours a day as possible in order to neutralize the injurious substances and make them harmless. With detention periods up to 20–24 hours the difference between the day and night flow is very small.

3. During long detention periods self-purification may be considerable. Whitehead and O'Shaugnessy have obtained 54.9 per cent reduction in soluble organic matter in an 18 hour period, as a result of bacterial action. In many cases, however, the effluents from plants having a long detention period may be worse than from those having a short detention period, because of the action of the digesting sludge. The soluble organic matter can be considerably reduced if settled sewage is permitted to stand for a long time.

4. The Royal Commission recommended that the dry weather tank and the biological part of the plant should treat three times the dry weather flow during storms. In addition the solids should be removed from an amount of mixed storm water and sewage equivalent to from three to six times the dry weather flow. Ordinarily the storm water tanks are empty and are only used when three times the dry weather flow is exceeded. After a storm the settled liquor is treated in the dry weather plant. Better results might be obtained if the dry weather tanks handled only up to about one and a half times the dry weather flow and with larger flows than this the storm water tanks would be put into operation. Then after a storm the contents of the storm water tank could be pumped to the plant designed for dry weather flows and treated by biological processes over a longer period.

Watson has designed the Mogden plant so that the effluent from the activated sludge plant continually flows through the storm water tanks. At the beginning of a storm the supply of effluent acts as a diluting water.

Long detention periods are desirable where plants handle large amounts of industrial wastes, where the sludge digests very poorly or where the solids have already been removed in preliminary tanks. The removal of solids from the mixed storm water and sewage is in many cases more beneficial to a stream than biological purification, which

is effective only during dry weather flows. For fresh sewage predominantly domestic in nature, small settling tanks with about a two-hour detention period are most desirable. If necessary, additional tanks furnishing 6 or even 12 hours detention for storm water flows may be constructed.

G. P. EDWARDS

SLUDGE DIGESTION AT SITTINGBOURNE

BY M. W. LASHMAR

Paper read at a meeting of the Institution of Sanitary Engineers at London, England, October 14, 1936 and reprinted—slightly condensed—in *The Surveyor*, **90**, 435–36 (October 16, 1936).

The new sewage works, opened in April, 1934, are designed to serve a population of 27,000 people and a dry weather flow of 675,000 g.p.d. The plant consists of bar screens, three grit channels in parallel, oil and grease interceptor, three two-story sedimentation tanks, activated sludge channel, final settlement tanks with separate sludge digestion and 4,115 sq. yds. of underdrained sludge drying beds.

Sludge Digestion Tanks.—Two arched digestion tanks are located between the sedimentation tanks each 57.5 ft. long and 19,171 cu. ft. capacity with floors shaped as two inverted pyramids where the digested sludge can be drawn off. Trapped inlets, 17 ft. from the ends, built into the arched roofs receive the sludge from the sedimentation tanks. Also three dome gas collectors with water seals are built along each roof. Hand-operated scum stirrers are also provided, as well as hot water piping around in the inside for heating the sludge. The gas collectors are connected to a gasometer having a capacity of 5,000 cu. ft.

Method of Operation.—The digestion tanks are operated in series being connected at their south ends. Raw sludge is introduced into the top of the primary tank at the north end inlet and the digested sludge withdrawn from he bottom of the secondary tank at the north end so that the sludge, during the digestion period, travels through the primary tank and back through the secondary tank. Supernatant liquor is drawn off daily from the outlet end of the secondary tank and then fresh sludge added to the primary. This supernatant is passed through a clinker bed where it is cooled and aerated before being returned to the crude sewage flow in order to avoid difficulties with the treatment process. Only the primary digestion tank is heated (to an average of 84° F.) which is sufficient to maintain an average temperature of 74° F. at the center of the secondary tank. Grease and oil from the interceptor is put in the primary digestion tank in which the scum stirrers are operated at least once daily. Digested sludge is removed as infrequently as possible, usually once each week.

Gas Production.—The gas produced in the digestors has varied from 1.47 to 0.338 cu. ft. per capita per day, the inconsistent volume being credited to the irregular discharges of trade waste which interfere with the working of the sedimentation tanks and result in an improper and irregular supply of fresh sludge. The gas has a calorific value of 700 B.T.U. and is used without any purification in a 36 b.h.p. oil/gas engine for driving the air compressor and in a gas heated boiler for the hot water circuits in the digestion tank. The engine is run at a speed of 250 r.p.m. producing 22 b.h.p., with an air pressure of 6¼ lb per sq. in., consuming an average of 425 cu. ft. of gas per hour or 19.76 cu. ft. per b.h.p. per hour. The gas boiler for the digestion tank heating uses an average of 6,113 cu. ft. per day.

It has not been possible to generate sufficient gas continuously for heating the digestion tanks and engine house in addition to that required for the engine, in which case the coke boilers are brought into use, although the average yield of gas for two years has been ample. These variations in volume of gas produced are ascribed to the deleterious effect on the digestion process of trade wastes in the sewage which contain sugar, china clay, glue, arsenic, lead, copper and sulphur. The origins of these wastes are to be traced in order that the harmful ones may be either excluded from the sewers or pretreated.

J. K. HOSKINS

INSTITUTE OF SEWAGE PURIFICATION. NORTHEASTERN BRANCH MEMBERS' INSPECTION OF ROTHERHAM DISPOSAL WORKS: DESCRIPTIVE DETAILS

PREPARED BY J. H. KERSHAW, Manager and Chemist

The Surveyor, 90, 295–96 (Sept. 11, 1936)

The sewage from the borough's population of 74,000, amounts to 2 m.g.d. or 27 gal. per capita including minor trade wastes. The main works are located at Aldwarke; two other small ones at Thorpe and Greasbrough treat the sewage from 2,000 and 4,000 persons respectively.

The original works constructed in 1902 provided for chemical precipitation, which process was never used in fact because treatment could be effected without the use of chemicals. Extensive alterations have been made in the plant since then. The present plant consists of detritus tanks and screens, primary settling tanks, bio-aeration treatment of the Haworth type, biological filters, humus tanks, storm tanks and sludge drying beds. The effluent is discharged to the River Don.

Detritus Tanks and Screens.—Two hopper shaped detritus tanks have a capacity of 60,000 gallons each and are used alternately for a week. Mechanical elevators discharge the sludge to tip wagons. Electrically driven mechanical screens of 150 sq. ft. area located at the outlet end of the tanks discharge screenings to a conveyor belt.

Primary Settling Tanks.—Six tanks, each 100×40 ft. in plan and 6 ft. deep are worked in two parallel sets of three in series. With capacities of 150,000 gallons each, they provide a detention period of 11–12 hours. Sloping floors cause the sludge to gravitate to a central channel and sludge well, from where it is pumped to an elevated tank for delivery to the drying beds. Floating arms on all tanks permit "top water" to be decanted when the tanks are cleaned.

Bio-aeration Plant.—Each of the two units is a tank 300×75 ft. in plan divided into 18 channels 4 ft. wide and 4.5 ft. water depth, and with a capacity of 550,000 gallons. Circulation is effected by motor-driven paddle wheels, 16 in one unit, 18 in the other, mounted on shafts which rotate at 15 r.p.m. Four Dortmund type settling tanks 32 ft. square and 23 ft. deep, each of 65,000 gallons capacity, serve each aeration unit. Sludge is evacuated through 6 in. pipes by hydrostatic head into chambers and thence flows to the sludge well. The bio-aeration plant has been in operation for over 12 years. From 10 to 15 per cent of sludge is carried in the channels.

Owing to the increasing strength of the sewage, the efficiency of treatment has decreased during dry periods especially. Reconditioning was effected by lengthening the aeration period, meanwhile by-passing all the sewage to the biological filters. More recently the effluent from the humus tanks is being returned to the bio-aeration tanks during dry weather, thus diluting the contents, so that reconditioning is no longer necessary.

Biological Filters.—Part of the settled sewage from the primary tanks is passed directly to circular filters, sixteen of which are 75 to 78 ft. in diameter and two 140 ft. in diameter, and all 4 to 5 ft. deep, composed of destructor clinker. Coal was used as a filtering material 35 years ago when the beds were first built. Although nearly all the coal has since been removed for fuel, that remaining shows practically no disintegration. The effluent from all filters flows to a well from which it is pumped to the humus tanks.

Humus Tanks.—Two tanks, 135×25 ft. in plan and 5 ft. depth have a capacity of 85,000 gallons each. They are provided with central sludge channels and floating arms.

Storm Tanks.—Two storm tanks, 200×50 ft. in plan and 5 ft. deep provide a six hour detention period when the flow is 2 m.g.d.

Sludge Disposal.—About 22,000 sq. yds. of sludge drying beds are provided, the drainage from which is returned to the incoming sewage flow. The dried sludge is placed on a tip for use of local farmers but little demand has resulted in a growing accumulation. The sludge disposal problem is not yet solved.

J. K. HOSKINS

THE SETTLEMENT AND RISING OF ACTIVATED SLUDGE

By J. A. McLachlan

Paper presented at the Annual Conference of the Institute of Sewage Purification, Exeter, England, July 3, 1936 and abstracted, with discussion, in *The Surveyor*, **90**, 39–41, 101–03, July 10, 24, 1936.

The Bruma works of Johannesburg, the first activated sludge plant of any large size in South Africa, has been in operation a year. The paper records laboratory studies on the settlement of activated sludge, the effect of various treatments on settling and discusses causes for the rising of sludge in settling tanks.

Bruma Purification Works.—The raw sewage, after passing through 1½″ bar screens is settled in two Dorr clarifiers and then is divided between two diffused air plants (one experimental) and bacteria beds. The settled effluent from the aeration plants is used to dilute that part of the primary tank effluent which is untreated, before the mixed liquor is distributed on the bacteria beds. The sprinkling filter effluent is settled in humus tanks, passed through secondary sand beds and then used for irrigation. The settled humus is returned to the reconditioning channels of the full-scale diffused air plant.

The experimental plant functions as an overloading plant and receives the surplus sludge; it can be operated with or without reconditioning of the sludge and is adjusted so as to treat a maximum flow of settled sewage without causing aerial nuisance. The overpowered sludge thus produced is returned to the inlet sewer and thereby prevents rising of the active surplus sludge in the Dorr clarifiers.

The activated sludge plant was installed for the specific purpose of eliminating odor and partially treating the liquor applied to the sprinkling filters. Experience has shown that odor can be eliminated only by maintaining a high concentration of nitrate in the activated sludge effluent. Such highly nitrifying sludge rises in the settling tanks recurrently, though no precise set of conditions can be definitely held responsible. Extended experiments were, therefore, conducted to investigate the problems of rising sludge and the reliability of settlement tests for plant control.

Sludge Settlement.—The experiments were devised to obtain information on specific points as follows:

1. The influence of the diameter of cylinder on the rate of settling of activated sludge. The results showed that, regardless of sludge density, settlement is generally more rapid in the narrow cylinders than in wider ones and most rapid in Imhoff cones, except where overpowered sludges were under test.

2. The effect on sludge settling produced by various dilutions with filtrate from activated sludge showed no striking increase at any dilution until the one-hour settlement was plotted against dilution, at which time the rate of settling increased rapidly with further dilution.

3. The relative effect on settlement by dilution with filtrate from activated sludge, primary tank effluent or distilled water was shown to be independent of the nature of the diluent.

4. The effect of electrolytes (coagulants) was generally favorable. Sodium chloride has a densifying effect on the sludge except on the overpowered sludge. Additions of sodium chloride and calcium chloride made little difference on the rate of settling but ferric chloride and potash alum caused immediate clotting into large flocs which settled within a minute to less than 50 per cent, from which it is concluded that the major effect is one of electrical charge rather than of osmosis.

5. In samples left standing for septic conditions to develop, the rate of settlement improved for eight days and afterward settlement became progressively less.

6. Additions of paper pulp suspension up to 0.5 per cent of the volume of the activated sludge resulted in a slight decrease in rate of settlement, 0.5 to 1.0 per cent increased the rate slightly and over 1.0 per cent caused a considerable decrease.

7. Results of experiments to ascertain the effects of concentration and addition of paper pulp on the settling of ferric hydroxide and on aluminum hydroxide confirmed those of Clifford and Windridge and the author agrees that any particles which have the same physical characteristics as activated sludge will settle in a similar manner. How-

ever, he believes that excessive amounts of fungus filaments can change the physical condition of sludge floc and contribute to bulking.

Rising of Sludge.—Causes for discharge of suspended solids from the settling tanks in the clarified effluent are discussed and bulking and rising sludge are differentiated. Rising sludge is characterized by the separation of large flocs from the settled sludge, which, in rising may cause the whole sludge to rise to the surface. It is light in color, of loose texture and low density, contains no excessive filamentous growths and restricted varieties of protozoa which in general show less activity than normal sludge. The release of minute bubbles of gas is pronounced, which O'Shaughnessy and Hewitt have demonstrated to be of gaseous nitrogen liberated from highly nitrifying sludge in the absence of dissolved oxygen, and frequently in sufficient volume to float the flocs in which it is generated.

The author, from results of his own experiments, confirms this conclusion as the immediate cause of rising sludge and suggests that the rapidity of rising must be related to the concentration of oxidized nitrogen, which in turn depends upon the concentration of nitrogenous compounds in the original sewage. Whatever the origin of the entrained gas, any form of mechanical shock or agitation would tend to liberate it from the sludge particles and thus prevent rising. Addition of electrostatic charges to the sludge particles were attempted but gave no promising result. Other methods are to be tried out.

Discussion.—Mr. W. T. Lockett (West Middlesex) had experienced few variations in settling qualities of sludge at his plant. With the establishment of nitrification conditions the density had increased until with well nitrified effluents the sludge, after one hour settling, contained over 2 per cent total solids, a condition which he ascribed to the thoroughly activated state of the sludge. No sludge rising had occurred although the relative quantities of nitrites and nitrates had varied widely. This he ascribed partly at least to the fact that the aeration channel units were long and little short circuiting of flow was possible whereby a mixture of well- and under-activated sludges could reach the settling tanks. He concluded that a plant designed to eliminate short circuiting in the highest degree would probably experience the least amount of sludge rising. He questioned that advisability of adding humus from the percolating filters to the activated sludge plant without reconditioning, because such humus would not be converted into well activated sludge in one passage through the aeration unit.

Mr. J. Hurley (Wolverhampton) questioned any material advantage to be obtained by returning overpowered sludge to the incoming raw sewage. Much of the improvement claimed for this practice of returning surplus activated sludge was probably due to the diluting effect of the purified liquor which was associated with the returned sludge. He had found that what was gained by decreasing the strength was lost in increasing the volume although the procedure was often justified from the standpoint of concentrating the surplus activated sludge. He took exception to the application of the results of some of the settling experiments to actual practice, for example the mixing of primary sewage tank effluent with activated sludge effluent before it passed through the sedimentation pockets. He also raised the question as to whether the difference in specific gravity of the liquid, however slight, might not be sufficient to have some influence on settlement or rising. He observed that rising occurred with sewages high in dissolved solids and that at Wolverhampton with sewage containing 2000 p.p.m. of sodium sulphate they suspected this factor as contributing to poor settlement of the sludge. He emphasized the importance of distinguishing between bulking and rising sludge as discussed by the author.

Dr. A. Key (Inst. of Gas Engineers) in a discussion of the time and causes of rising suggested that rising could be controlled either by retarding purification so as to ensure absence of nitrite and nitrate or by effecting complete purification with high dissolved oxygen content of the sludge-sewage mixture and a low oxygen demand of the sludge.

Mr. H. C. Whitehead (Birmingham) remarked that as a result of the observations of Mr. O'Shaughnessy and himself concerning the crystalline inorganic matter contained in all activated sludges, they had determined that the addition of marl would increase the inorganic content of activated sludge and thereby improve settling. The obvious procedure for correction of light sludge was to add ballast.

Dr. W. Rudolfs (New Jersey Exp. Station) suggested that, from an examination of

the gas analyses, either CO_2 or nitrogen gas might be the causative factor in sludge flotation, depending upon the sample being dealt with. A combination of CO_2 and nitrogen seemed to be most productive of sludge rising.

Mr. A. Holroyd (Dagmham) had found that his plant worked better and on a higher flow when nitrification was retarded, confirming the observations of the author. He raised the point as to whether the activated sludge was not the wrong process for the production of nitrified effluents, because it led to no end of difficulties. He inquired if the high elevation of Johannesburg with the consequent effect on the oxygen content in the actual plant might not have had an influence on the author's experimental results.

Mr. J. M. Wishart (Shipley) asked whether any work had been done to ascertain if a specific organism produced nitrogen from nitrites and nitrates. None had been done.

J. K. HOSKINS

THE PURIFICATION AND DISPOSAL OF GAS LIQUORS

BY J. H. GARNER AND J. M. WISHART

Report of West Riding of Yorkshire Rivers Board. *The Surveyor*, 90, 287–88 (September 11, 1936).

Further experiments on the purification of wastes discharged from gasworks are described.

Although gas liquor should only be admitted to sewers in exceptional cases because sudden discharges of it interfere seriously with biological processes unless the volume of sewage permits sufficient dilution, the admission of the liquor at a uniform rate of flow with concentrations up to 1.0 per cent do not seriously interfere with the normal process of biological filtration. The addition of gas liquor slows down the rate of biological filtration, so increased filter capacity is necessary. Certain examples show in practice that the liquor is first passed through a special filter to remove all traces of tar before it is discharged at a controlled rate to the sewer.

The report regards as "unduly optimistic" the statement given twenty years ago in the ninth report of the Royal Commission on Sewage Disposal that gas liquors up to 2 per cent of the volume of sewage can be discharged safely into the sewers.

Experiments revealed that "the main oxygen absorbing constituents of gas liquors are phenols, and that the chief processes of purification in biological filtration are the oxidation of the bulk of the phenols and the nitrification of part of the ammoniacal compounds." Concentrations of 0.5 to 1.0 per cent can be treated at a uniform rate of 70 gallons per cubic yard per 24 hours, with phenol content reduced from 60 to 70 per cent and "oxygen absorbed" reduced from 40 to 50 per cent. The addition of formaldehyde was found to remove sulphides and thiocyanates, but this method had no advantage over boiling.

The following other possible methods are mentioned: Evaporation of spent liquor at the gasworks by using waste heat and fuel; partial purification by dephenolization; and the "Parkes process" in which the treated liquor is filtered through activated carbon for the removal of phenols which are afterward recovered by steam distillation.

JAMES H. LE VAN

AERO-FILTRATION OF SEWAGE AND INDUSTRIAL WASTES

BY H. O. HALVORSON

Water Works and Sewerage, 83, 307–13 (September, 1936)

Current Practices.—Filters are from 6 to 8 feet deep, with a filter medium of rock graded from a minimum of ¾ to a maximum of 3 inches. Underdrains are provided beneath the rock to carry away water and to allow for aeration. Fixed nozzles have been used, but some of their difficulties in securing good distribution have been overcome by

using rotary distributors. Intermittent operation has always been taught as being essential for successful operation. Standard practice has dictated that the filter bed should be dosed at rates from ½ to 4 million gallons per acre of surface per day.

To secure these results the universal practice has been to precede the filter by a dosing tank operated by means of a siphon. It is assumed that liquid passing through a filter takes the shape of a cone and that aeration is automatically taken care of by the intermittent dosage.

Comments in Review.—These standard practices do not appear to be founded on fundamental principles. Micro-organisms grow faster and thrive better when fed continuously. Better distribution of liquid occurs with a continuous light flow. In the development of the trickling filter, the rate of 6,000 to 10,000 gallons per acre per day was used with soil as a filter medium, an underdrainage system, and intermittent dosage, and this rate was used successfully for 40 years. Later it was learned that rock or cinders would purify as well the intermittent filtration bed, and that the entire surface of the bed could be flooded if sand were used. A rest period was found to be essential with contact beds, and that efficiency was increased as the number of dosing and resting periods were increased. To shorten the cycle would mean an overlapping of filling and draining periods.

The precedence in design and operation of the trickling filter apparently was established by the contact bed, and the use of the dosing tank aided in securing more even distribution, because orifices then (1898) needed a somewhat constant head to give a constant dosage. Thus, the intermittent principle was introduced as a mechanical and not a biological aid. The following facts appeared to be true:—Fine filtering material aids clogging, but even with a filtering medium of ⅛ to ½ inch, a dosage as high as 7 million gallons per acre per day could be used. A trickling filter can be operated without rest periods, but short rest periods probably do no harm. Distribution accuracy increases with coarser media.

Present Experiments.—It was found with a constant volume of liquid that the degree of purification can be increased by increasing the speed of the rotary distributor; or, with an increased volume of liquid the degree of purification can be kept constant by increasing the speed of the distributor. After a rotary distributor reached its normal speed, there was very little unloading, which brought out the theory that a bed dosed continuously with a rain-like spray might work efficiently at high enough rates to provide a flushing action that would wash out slime or sludge, although this bed at lower rates might pond. Experiments have shown that loading can be increased from 2 million to 20 million gallons per acre per day when properly applied, but a dosage from 7 to 10 million gallons per acre per day will cause ponding. Later experiments in air flow studies disclosed that the only factors that cause air to flow through a gravel "filter are the difference in the temperature of the air and the liquid, and the difference in humidity of the air in the filter and the air outside." The indications are that filters should be provided with forced draft when the temperatures of air and liquid are nearly equal, that is, spring and fall. Only a small amount of oxygen is needed to oxidize organic matter, but the rate of adsorption is important, so the minimum of forced draft has been set at 1 cu. ft. of air per sq. ft. of surface per minute. At doses above 10 million gallons per acre per day there was a straight line relationship between the rate of flow of air and the difference in temperature of liquid and air, but below 10 million gallons the relationship did not hold and the air flow was erratic.

Continuous dosing which keeps the filter surface wet at all times will keep flies from escaping from inside the bed. A filter medium made of specially designed tile when used with strong wastes makes unloading easier and thus prevents ponding. Inoculating the sewage daily with soil prevented growth of Fusaria, possibly because it carried an organism which parasitizes mold.

JAMES H. LE VAN

CHEMICAL PRECIPITATION STUDIES AT GRAND RAPIDS

By N. G. Damoose

Michigan Engineering Experiment Station, *Bulletin* **68**, 5 (May, 1936)

The additional costs necessary to add chemical treatment to the present treatment given to Grand Rapids sewage are presented in detail. All figures are based on 19 p.p.m. ferric chloride plus sufficient chlorine to give a 0.1 p.p.m. residual in the effluent. These costs per m.g. are $.61 for interest and amortization, $.33 service charge for two operators, $3.52 for ferric chloride and $2.33 for chlorine. If a credit of $30.59 per day ($7.00 per ton) is allowed for the additional fertilizer produced and $28.96 for the gas from digesting sludge, the estimated cost of additional treatment would be $4.38 per m.g. Estimates are also given for 5 methods of part time treatment; operation during 16 and 12 hours daily throughout the year and operation during 24, 16 and 12 hours daily during the period May 1st to October 31st. The cost per m.g. of total flow under these conditions compared to $6.79 for continuous treatment, would be, respectively $4.85, $3.88, $3.89, $2.91 and $2.42.

R. W. Kehr

INTERESTING FEATURES OF NEW PLANTS IN MICHIGAN

By E. D. Rich

Michigan Engineering Experiment Station, *Bulletin* **68**, 10 (May, 1936)

Separate digestion plants have been built in preference to Imhoff tanks except in small installations. Comminutors with bar screen bypasses are being constructed at two new plants. Grit is being handled by grit chambers with constant velocity weirs or by detritors. Sedimentation tank design in circular clarifiers includes central feed with circumferential collection and a shallow scum baffle placed about 1 ft. in front of a notched weir. In rectangular sedimentation tanks with mechanical removal of sludge, some effluent weirs are in the form of the letter H, consisting of two side troughs and a cross trough near the outlet end. Scum removal at one plant is to be handled by a slotted 12 in. aluminum pipe which can be rotated to bring the slot to the water level.

Two stage sludge digestion with gravity flow from the first to the second tank is provided at one plant. In this case supernatant liquor is drawn only from the second tank and the first tank is agitated. Sliding sleeve drawoffs for sludge control are provided in two new plants. Odor control at one plant is provided by forced draft through a 60 ft. steel stack of the "flag-pole" type.

R. W. Kehr

CHEMICAL PRECIPITATION TO MEET DILUTION DEMANDS

By C. K. Calvert

Michigan Engineering Experiment Statian, *Bulletin* **68**, 44 (May, 1936)

The revival of chemical treatment is not due to the discovery of a new chemical agent, but to such factors as lower prices of chemicals, improvement in methods of handling chemicals, development of sludge drying equipment and the proper handling of treated sewages. All of these have encouraged engineers of ability and repute to investigate the possibilities of chemical treatment to meet varying conditions of load and diluting water. "It is well established that sewage treatment should be carried only to such an extent as is required to meet the demand of the receiving water." Much more complete treatment is required, however, if recreational facilities, or a municipal water supply is involved, than if merely avoiding nuisance is all that is necessary.

Under conditions of part-time chemical treatment, costs may be lower than biologic

processes, but when compared on the basis of cost per thousand pounds of B.O.D. removed, it will be found that chemical treatment is expensive in its operation compared to biologic plants, even including fixed charges which are very much higher in the biologic plants. At Indianapolis, the cost of removing 1000 pounds of B.O.D. in the enlarged plant will be $2.26 for operation and $4.23 for interest and depreciation, a total of $6.49, which would rise to $10.72 for summer operation alone. At another large activated sludge plant, operating costs were $5.00 per thousand pounds of B.O.D. removed. Compared with this, cost data per thousand pounds of B.O.D. removed in several chemical precipitation plants are as follows: $59.15 estimated for summer only at Grand Rapids; $17.43 estimated for chemicals alone at Shades Valley; $19.93 for chemicals alone at Coney Island; $4.77 for chemicals alone at Dearborn with low chemical prices or $6.86 at Dearborn if $FeCl_3$ is assumed to cost 2 cents per pound and lime at $12.00 per ton.

The quantity of dry solids to be handled is greater in chemically precipitated sludge, which may be of higher water content than sludge from plain sedimentation.

Chemical precipitation requires as much or more technical supervision than biologic processes but the operating force is more easily trained than the shift men necessary to operate an activated sludge plant.

"As an important tool, chemical precipitation is here to stay, this time, and no doubt will be used sanely, and as it should be."

R. W. KEHR

THE EFFECT OF GROUND GARBAGE ON SEWAGE AND THE SEWAGE TREATMENT PLANT

BY S. L. TOLMAN

Michigan Engineering Experiment Station, *Bulletin* **68**, 19 (May, 1936)

Indianapolis sewage is given plain aeration in an activated-sludge type plant with sludge disposal by digestion in a lagoon. Waste liquors from the garbage reduction plant, totalling 70 lbs. of B.O.D. per ton of garbage were disposed of by lagooning with the sludge. Following an explosion in the garbage reduction plant in May, 1935, a temporary garbage grinding station was hurriedly erected and has since then been used to dispose of garbage into the raw sewage at the sewage treatment plant.

Indianapolis green garbage produces, per ton of garbage, 38.2 lbs. of grit with 28 per cent moisture content, or about ¼ to ½ of the sewage grit; 3.1 lbs of bones and 3.4 lbs. of metal hand picked; 350 lbs. suspended solids; 153 lbs. B.O.D.; and 7.6 lbs. of organic nitrogen.

Fine grinding, ¼ inch, eliminated the floating matter which was present with ¾ inch grinding. Garbage grinding caused increases as follows in the raw sewage and settled sewage, respectively: total solids 11 per cent and 5 per cent; suspended solids 27 per cent and 6.3 per cent; B.O.D. 34 per cent and 25 per cent; total organic nitrogen 10 per cent and 4.5 per cent; petroleum ether-soluble 34 per cent and 10 per cent. All of these figures were based on the average increase during 8–12 hours daily grinding over the period June 3rd to December 14th, 1935. It is estimated 14 per cent of the primary sludge was due to garbage solids.

There was no particular difficulty in handling the sewage-garbage mixtures in one unit of the plant operated as an activated sludge plant. Under the conditions at Indianapolis, garbage grinding costs $.301 per ton and increased operating costs for sewage disposal $.204 per ton of garbage.

From a financial standpoint, such increase in sewage plant cost as occurs on account of the ground garbage will leave a favorable margin in the difference between grinding and customary garbage disposal costs.

R. W. KEHR

BEET SUGAR WASTES AND THEIR TREATMENT

By E. F. Eldridge

Michigan Engineering Experiment Station, *Bulletin* **68**, 14 (May, 1936)

The average Michigan factory slices about 1300 tons of beets per day, and produces about 4 million gallons of wastes with a total B.O.D. of 60,000 pounds per day. About 75 per cent of the B.O.D. is from Steffens waste, 15 per cent from process water, 8 per cent from flume water and 2 per cent from lime water. All factories in Michigan produce wastes with a population equivalent of 2 million or about ½ the population of Michigan.

Experiments made in a 100,000 gallon per day experimental plant at Bay City, have led to the following conclusions: (1) flume water treatment should consist of continuous grit removal (800 cu. ft./mg.) and 1.5 to 2 hours sedimentation in mechanical clarifiers; (2) process water should be coagulated with 600 p.p.m. CaO and settled 1.5 to 2 hours; (3) biological filtration of these wastes is not economical; (4) sludges may be vacuum filtered at a rate of 100 gallons per sq. ft. per day; (5) lime cake should be disposed of separately and cannot be used for coagulation; (7) Steffens waste is an excellent coagulating agent but residual B.O.D.'s are high.

A 1 million gallon per day semi-experimental unit is to be constructed and will include a full scale study of spray drying of Steffens wastes with waste flue gasses and attempted recovery of valuable by-products.

R. W. Kehr

WHAT IS A GOOD SEWAGE TREATMENT PLANT?

By G. B. Gascoigne

Michigan Engineering Experiment Station, *Bulletin* **68**, 55 (May, 1936)

The ideal sewage treatment plant location should be inconspicuous, should allow ample room for expansion and should have a favorable elevation. The treatment chosen and the size of plant should be sufficient to prevent nuisance, preserve fish life and safeguard water used for recreation and potable purposes. The dilution requirements for various methods of treatment, estimated to leave a minimum residual dissolved oxygen of 2 p.p.m. in the receiving stream, are given in the table below:

Kind of Sewage	Type of Treatment	Degree of Purification Per Cent	Dilution Required C.F.S. per 1000 Persons
Raw or coarse screened	Preparatory	5—	6.0
Fine screened	Preparatory	8	5.5
Fine screened and chlorinated	Preparatory and germicidal	20	4.8
Settled	Partial	35	3.9
Settled and chlorinated	Partial and germicidal	50	3.0
Clarified	Colloidal	65	2.1
Clarified and chlorinated	Colloidal and germicidal	70	1.8
Completely treated	Oxidation	85–92	0.5

R. W. Kehr

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